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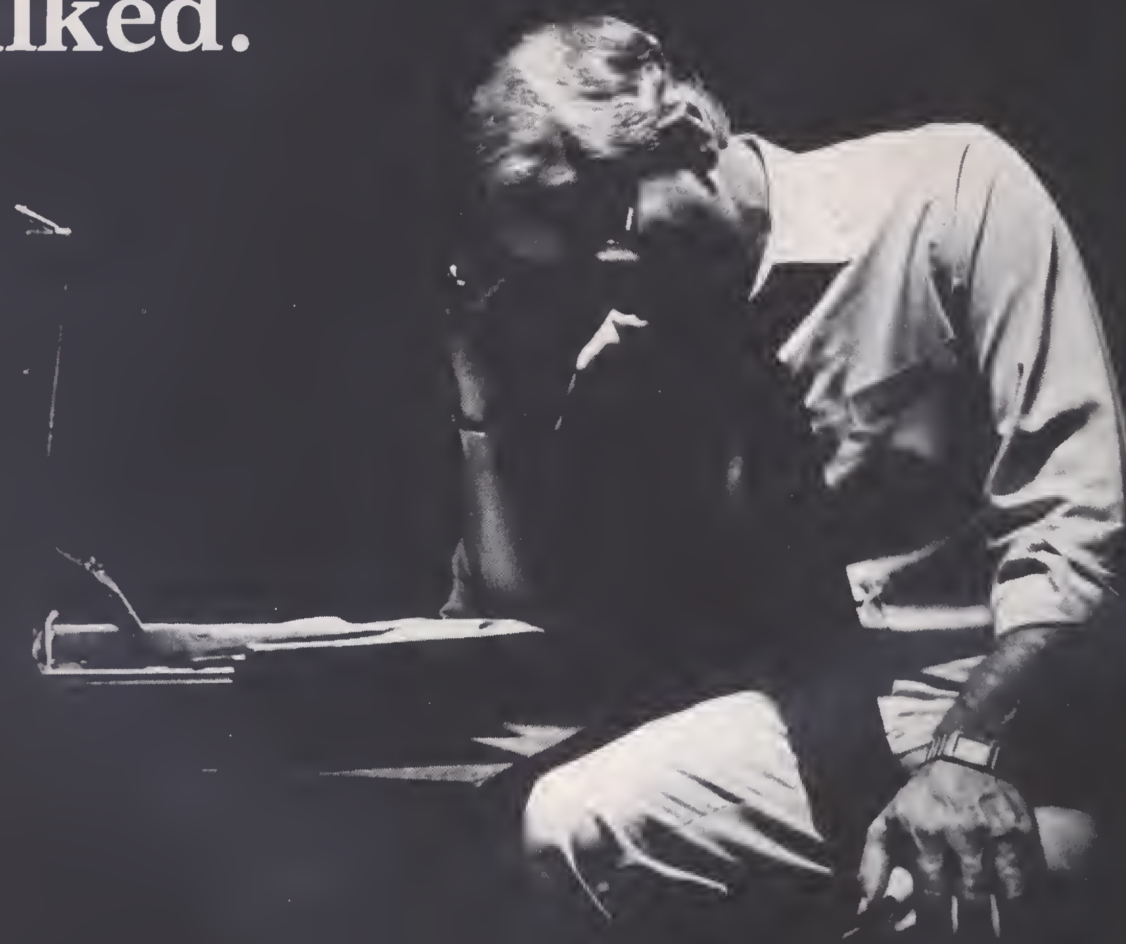

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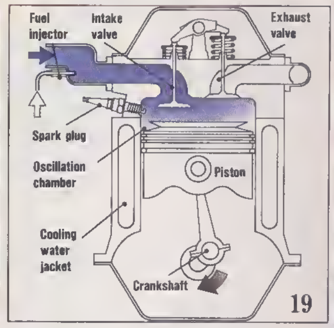

FEATURES

DEPARTMENTS

Cover Feature-based part models from GE R&D Center (top left), Ingersoll Milling Machine (top right), and Automation Technology Products (bottom right). Bottom left: Finite-element method automates stress analysis (Automation Technology Products).

OPINION

Too Much Bureaucracy Could Scuttle The Space Station

One would think that all the investigations in the wake of the *Challenger* disaster would have taught us something about the management of complex projects. Because of the focus on safety issues, however, some vital lessons seem to have been missed.

Policymakers had a chance to see how decisionmaking concerning the Space Shuttle led to a compromise system ideal for neither military nor commercial use (HIGH TECHNOLOGY, June 1986, p. 38). And investigators saw how a bureaucratic structure in which managers could ignore advice from technically knowledgeable engineers led to calamity.

KAREN STOLPER

Why not apply these lessons to the nation's next mammoth space project, the manned space station? In addition to military influence, which compromised the shuttle's design, this program involves some European nations, along with Canada and Japan—all of which are now pushing for a stronger say in its development. Thus the system is likely to be designed by politics rather than technology. Meanwhile, the Soviets have about a 10-year lead in space station design and operation.

In a recent speech, H. Ross Perot, chairman of Electronic Data Systems in Dallas (and at the time a GM board member), asked his audience to imagine that man had not yet figured out how to fly. As a national enterprise, the U.S. embarks on a program to learn how, and NASA is created to implement the bold project. Picture, he suggested, a large NASA office where two young men come in and ask for support to build a flying machine. When the NASA official learns that the men run a bicycle repair shop, and that neither has a degree, he politely sends them on their way. Most likely, the Wrights would have had a plane in the air while NASA was still evaluating costly proposals and filing fat progress reports.

The United States should consider a whole new approach to this kind of project. Let's recognize that bureaucracies don't create new technology; imaginative, enterprising people do. So why not appoint a successful technology problem solver to direct the space station program—someone like Burt Rutan, the designer of the *Voyager*, the first aircraft to fly around the globe without refueling? Let Burt get whatever help he needs from the best sources—be they NASA, aerospace companies, or even other countries. Let him pick a couple of sharp technical deputies to assist in attaining all the program's commercial, scientific, and military goals. Then let's get out of the way so that someone who knows how to get things done can do the job. The bureaucrats could still play a role, interviewing Burt and his deputies occasionally to prepare the lengthy reports required by oversight committees, foreign partners, and so on. This way, Rutan's group could be designing a space station rather than doing paperwork.

It may sound draconian, but with our present direction we can expect huge cost overruns and delays as NASA, the Pentagon, and several countries push and pull to get their way. That will be followed by congressional investigations to find out what went wrong. Sound familiar?

Robert Haavind

Robert Haavind

HIGH TECHNOLOGY

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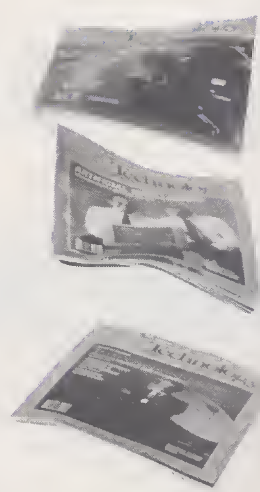

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ment that it offers. But I have a concern regarding its exhaust emissions. Will pulse furnaces produce more oxides of nitrogen than conventional gas-fired home-heating furnaces? If so, it will be of no help if we accustom ourselves to the pulse furnace's efficiency, only to have to revert to more conventional equipment

the primary measure of the quality of a modern building. Conservation is an important objective, but it should not take precedence over human health.

Karen Adelson Strauss
Environmental Engineer
Ellicott City, Md.

Dalhousie University
Halifax, Nova Scotia

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Robert Haavind

KAREN STOLPER

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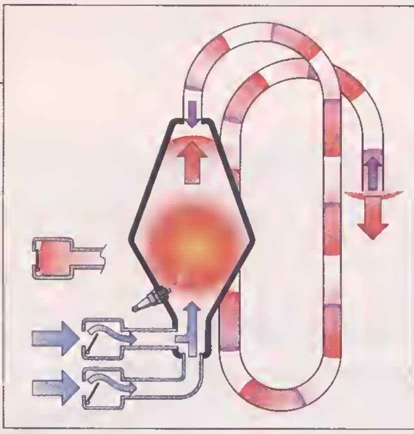

Firing 60–70 times or second, the pulse furnace offers efficiencies of up to 97%, plus low emissions.

Getting to the bottom of home-heating systems

In "Home-heating advances save energy dollars" (March 1987, p. 57) you mention that the National Rural Electric Cooperative Association (NRECA) in Washington, D.C., is sponsoring experiments with earth-coupled heat pumps for rural electric systems. We are one of the participants in experiments by the NRECA and presently manufacture and install the only direct-expansion ground source heat pump commercially available in the U.S. As with other "overnight success" products, ours has been available for 10 years. It has been used to provide heat not only for residential space, but for other applications such as offices, commercial greenhouses, and swimming pools. We have sold over 250 operating units and have never had one of our systems replaced with another heating system.

James J. Jungwirth, President
Sub Terra Ground Heat Systems
Newberg, Ore.

In your article on home-heating advances, I am intrigued by the concept of the pulse furnace and the fuel-efficiency improvement that it offers. But I have a concern regarding its exhaust emissions. Will pulse furnaces produce more oxides of nitrogen than conventional gas-fired home-heating furnaces? If so, it will be of no help if we accustom ourselves to the pulse furnace's efficiency, only to have to revert to more conventional equipment when the EPA finds its NO_x characteristics unsatisfactory.

Alexander R. Kovnat
Oak Park, Mich.

Editor's note: According to the American Gas Association, pulse furnaces emit less than half the NO_x of conventional gas units. The pulse system's high efficiency does not come from a hotter flame, which would indeed increase NO_x output; rather, the turbulence created by the pulses prevents the formation of a layer of thermally insulating gas on the walls of the combustion chamber, allowing more heat to be transferred to the airstream.

ILLUSTRATION BY MARK ALSOP

Wanted: health-wise buildings

Your article "Energy-wise building" (Feb. 1987, p. 36) unfortunately gives short shrift to critical health implications of efficiency. Most energy in a building is saved through such non–high tech activites as reducing air exchanges and lighting costs (either with less light or different types of lighting). These solutions entail significant health consequences. The "sick building" syndrome, in which a wide variety of air pollutants are concentrated by reduced air-exchange rates, is presumably cured by using air-to-air heat exchangers, but few buildings—residential or commercial—employ them. And tests often find these exchangers ineffective in returning air quality to earlier "pretight" levels, without unacceptable energy costs.

In addition, research on the relationship between lighting and human health indicates that reduced levels of lighting, and the quality of lighting associated with many high-efficiency light bulbs, have unpleasant physiological and psychological consequences. People, it turns out, are very sensitive to the nature of light in their daily environment.

Energy efficiency is necessary, but not the primary measure of the quality of a modern building. Conservation is an important objective, but it should not take precedence over human health.

Karen Adelson Strauss
Environmental Engineer
Ellicott City, Md.

More parallel processors

We were surprised to note that your article "Parallel computers diverge" (Feb. 1987, p. 16) did not mention Control Data Corporation's Cyberplus parallel-processing system.

We have had a three-box Cyberplus system in operation for over a year at the University of Georgia. The peak performance of our system is rated at 330 MFLOPS (32-bit arithmetic). We acquired this system to anticipate problems that might be encountered during migration to our planned parallel/vector processing system, the ETA[10]. While software development still has a long way to go, we find that the Cyberplus is superior to our Cyber 205 vector processor for a few specific applications.

Charles F. Bender, Director
Advanced Computational Methods Ctr.
University of Georgia
Athens, Ga.

Your article on parallel processing stated that you didn't see "any evidence that either IBM or DEC are anywhere near releasing a true parallel-processing architecture." The IBM 3090, commonly called the Sierra, was introduced over a year ago, and is indeed a true parallel processor that currently has up to four processors in a full configuration. Parallelism is enforced through the compiler, which allows the partitioning of one user job across these four processors. So far, nearly 1000 Sierra computers have been sold. DEC has been working for some time in designing software so that a VAX cluster can act as a true parallel processor. Coarse-grain parallelism is legitimized by the involvement of manufacturers such as IBM and DEC, and is available to the general user. It's definitely here to stay.

K. J. M. Moriarty
Department of Mathematics, Statistics, and Computing Science
Dalhousie University
Halifax, Nova Scotia

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INNOVATIONS

Real 3-D graphics

When makers of engineering workstations speak of "3-D graphics," what they really mean is 2-D images rendered in perspective. The first commercial workstation to offer true, stereoscopic 3-D (claims the manufacturer) is the 4126 color-graphics system, recently introduced by Tektronix of Beaverton, Ore. The system is intended for applications such as CAD/CAM, geophysical engineering, and molecular modeling, in which users must ordinarily view a series of images at different angles in order to conceptualize an object's shape. The basic 4126 workstation, selling for $29,950, includes 2 megabytes of memory and a 19-inch CRT display with 1280 × 1024–pixel resolution.

To achieve the stereo effect, the display alternates between two images, slightly offset from one another, at a rate of 57.5 times a second. A pair of filters in front of the screen perform "circular polarization," causing lightwaves from the images to rotate. With each alternation of the images, a third filter—a liquid crystal "shutter"—changes the direction in which the light rotates. As a result, the user, who wears special glasses, sees one image with the right eye and the other with the left; the brain does the rest, fusing them into a single, flicker-free 3-D picture.

The workstation, which can run software for earlier Tektronix systems without modification, displays from 16 to 256 colors simultaneously, and an optional feature allows shaded-surface modeling in addition to the standard wire-frame line drawings.

Headphones cancel noise

In the din of an aircraft or a factory, it can be difficult to hear the relatively feeble sounds trickling out of a communications headset. But loudspeaker manufacturer Bose (Framingham, Mass.), with funding from the Air Force, has developed a new headset that electronically erases noise so that the wearer can hear radio messages clearly.

The Bose unit monitors the sound inside the earcup, continuously comparing it with what the wearer is supposed to be hearing—either a communications signal or silence. In response, the system generates an "anti-noise" waveform, with peaks and troughs exactly out of phase with those in the noise (defined as the difference between the sound in the earcup and the reference). This signal drives a speaker in the earcup, producing sound waves that cancel out the unwanted ones.

Testing Bose's noisebuster on Voyager *(l–r): pilots Jeana Yeager and Dick Rutan, Bose engineering manager Dan Gauger.*

The technique works against the low frequencies (below 1000 hertz) produced by common noisemakers such as engines, wind, and ventilation systems. Noise is reduced by as much as 25 decibels, according to Bose—enough to dull the roar of a subway train to the level of a vacuum cleaner. Not only does such muffling make communication easier, but it reduces fatigue and may avert ear damage, says biomedical engineer Richard McKinley of the Armstrong Aerospace Medical Research Laboratory at Ohio's Wright-Patterson Air Force Base.

In March, fighter pilots at Edwards Air Force Base in California began using experimental versions of the headset; the Bose phones have also been tested by Navy and Army operators of helicopters, tanks, and small aircraft. And last December, the headsets guarded the ears of *Voyager* pilots Dick Rutan and Jeana Yeager during their record-setting flight around the world. Bose hopes eventually to market the patented phones for industrial as well as aerospace use.

Technology training for kids

Wood shop and home economics, for years the mainstays of industrial arts training in junior high schools, may soon give way to a comprehensive course in technology. Twenty-six states are considering the move, and some, like New York, have already adopted a mandatory one-year program.

The goal of the New York program, begun in September 1986, is "to develop technological literacy as part of all students' fundamental education," says Michael Hacker, associate state supervisor for technology education. It was felt that the industrial arts courses did not adequately prepare students for coping with the rapidly changing workplace or with advances in consumer technology. The replacement course aims to help students understand new technologies such as factory automation, as well as the process of putting novel ideas to work.

To achieve these goals, the course requires lots of hands-on experience. Students learn to use computers, and spend much of their time using shop tools to build devices that solve a particular problem. In one section, students must build a model rocket that can reach an altitude of 500 feet. After the teacher introduces them to the principles of rocketry, the students watch a model being launched. Then they design and construct their own. As in industry R&D, they test their models and note any changes that need to be made. Finally, the students launch their projects. Afterwards, they study the history of rockets and compare them with other modes of flight.

The benefit of this approach, says Henry Harms, who teaches the course at Great Hollow Intermediate School in Nesconset, N.Y., is that the students "have to think and do, not just do." Harms says student reaction to the program has been good.

Strong ceramics without heat

Ceramics such as aluminum oxide, which are tough enough to stand up in a wide range of industrial applications, must be formed at high temperatures and pressures. But a new class of materials that reportedly possess similar physical properties offer a distinct advantage: they harden at room temperature. Called chemically bonded ceramics (CBCs), they were developed by Cemcom Research Associates in Lanham, Md.

According to Cemcom research director David Double, the materials consist of a proprietary blend of powdered mineral oxides, silicates, aluminates, and other substances found in naturally hard structures such as shells and rocks. Like the minerals that make up cement, these ingredients form tough chemical bonds when mixed with water. But unlike cement, which fails at only about 7000 pounds per square inch, CBCs can be formulated to withstand 70,000 psi. Their properties may be varied through the addition of polymers that promote bonding, as well as an assortment of other materials. In one recipe, steel particles make the ceramic strong enough to be used in tool molds. In another, graphite imparts abrasion resistance for use in brake linings.

Cemcom is now looking for corporate partners to help develop other CBC applications, such as military-vehicle parts, nonconductive electrical fixtures, and new building materials.

DNA probe homes in on gum disease

Until recently, there was no accurate way to diagnose periodontal disease—which afflicts the gums of 23 million Americans—before it had reached an advanced stage. Now, BioTechnica Diagnostics (Cambridge, Mass.) offers a simple, speedy test using a DNA probe. Such probes, fast becoming important medical tools, consist of single strands of DNA synthesized to match complementary strands in target organisms.

Before the test is performed, a dental hygienist inserts a toothpick-like blotter between the patient's gum and teeth, and mails this sample to the Cambridge lab. There the sample is heated to split all DNA molecules down the middle, and then mixed with the probe. The DNA strands in the probe, which was developed jointly with Forsyth Dental Center in Boston, are designed to link up only with strands in those bacteria that cause periodontal disease. If any such bacteria are present in the sample, they can easily be detected, since the probe is radioactively labeled.

Ordinarily, periodontal disease is not detected until the gums are sore and bleeding or x-rays reveal bone deterioration. By then, it is usually too late for the patient to avoid painful surgery that costs an average of $1500—and that may have to be repeated, since the disease often recurs. By contrast, the $75–$100 BioTechnica test can often spot the disease early enough for antibiotics to do the trick.

Eugene Savitt, BioTechnica's director of dental research, says the kit is now being used in Massachusetts and Connecticut and is expected to be available nationally sometime this month. He estimates potential revenues at $100 million a year.

Telling motorists where to go

The fastest way to get from point A to point B is with a good, clear set of directions. That's the philosophy that spawned Driverguide, an electronic way-finder soon to be sold in both stationary and mobile versions. Unlike current navigation systems, which display a vehicle's location on a video screen map, the new unit from Karlin & Collins of Sunnyvale, Cal., tells drivers where to turn, what landmarks to look for, and how long the trip should take. In the best tradition of gas station attendants, it takes into account such hindrances as one-way streets and left-turn restrictions, and it even contains data on speed limits and a complete listing of street addresses.

The system's databases, each covering a wide region such as the six counties of the San Francisco Bay area, are contained in memory chips attached to interchangeable cards. A driver simply enters starting points and destinations via a keypad, and directions are displayed on the unit's screen. The first version of Driverguide, a stationary model being introduced in major metropolitan areas this spring, also provides a printout. Intended for hotel lobbies, car rental agencies, and other places where motorists commonly seek directions, this model is priced between $5000 and $12,000, depending on volume.

Later this year, Karlin & Collins will release two other versions—one for cars (*sans* printer), selling for about $1000, and one for vehicle fleets, to be leased for about $150 per month plus 20¢ per use. The firm is also working with a U.S. automaker (industry sources say Ford) on an original-equipment version with a flat-panel display for a 1990-model car.

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  RESTAURANT AT 4045 MAPLE ST --
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* DRIVE 0.1 MILES ON MICHIGAN (US-12) TO A
  TURN-AROUND
* MAKE A U-TURN AS SOON AS POSSIBLE

* DRIVE 4.8 MILES ON MICHIGAN (US-12) TO MAPLE ST
* TURN RIGHT ONTO MAPLE

* DRIVE 0.3 MILES ON MAPLE TO 4045 MAPLE ST
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Driverguide gives step-by-step directions between any two points in its area of coverage. Above right: an actual printout (shown smaller than life-size).

COURTESY KARLIN & COLLINS

PHOTOVOLTAICS: A WORTHY INVESTMENT

BY KENNETH ZWEIBEL
MANAGER, POLYCRYSTALLINE THIN FILMS
SOLAR ENERGY RESEARCH INSTITUTE

Over the past decade, research has been carried out to develop photovoltaic (PV) devices—otherwise known as solar cells—tailored to low-cost electricity. Great progress has been made over a wide front, with several new technologies now emerging that could satisfy a significant portion of our nation's electrical needs. But the U.S. position in PV is fragile, and progress could slow down for reasons that have little to do with the technologies themselves or their commercial possibilities.

The solar cell is a semiconductor device that converts sunlight directly into electricity. Photovoltaics have been used for powering satellites since the dawn of the space age. The idea of using them to produce electricity on earth is also fairly old, but to do that inexpensively has been a daunting challenge: it has required a cost reduction of about three orders of magnitude from that of space-based PV. Nevertheless, the current cost of PV-generated power is less than one order of magnitude from that of conventional electricity, and it is falling fast.

Although low-cost solar cells for utilities are not yet available, we do have scientific evidence that they can eventually make the grade. The question is not whether we can do it, but how to get there from here with sufficient speed. Funding from the Department of Energy, for example, has fallen from about $150 million in 1980 to about $40 million in the present fiscal year. Moreover, strong U.S. progress in the private sector is dependent on the efforts of a few undercapitalized small businesses and some oil company subsidiaries that are vulnerable to oil price fluctuations.

In Japan, meanwhile, the government allocates about the same funding to PV as that of the U.S. government, but there is a more substantial commitment of capital from private industries. In Europe, funding has increased since Chernobyl—about $45 million is being considered for new PV technologies. Thus the U.S. may wind up second (or even third) in developing PV, a prospect with unpleasant economic implications.

There are many incentives for using solar cells on a large scale: they do not pollute, they do not contribute to the green-

house effect, they present no waste disposal problems, they reduce our dependence on foreign energy suppliers, and they are attractive on economic criteria alone. The eventual domestic market for utility PV could be worth billions of dollars each year, and there is potential for an enormous export market to third world countries for PV-generated village power. Moreover, the solid-state R&D needed to make commercial solar cells a reality puts us squarely into some of the most sophisticated semiconductor research as well, thereby promising manifold advances in electronics well beyond the solar-energy arena.

Electric utilities in particular could realize many operational advantages in adopting PV. It is well matched to peak daytime electricity demands, for instance, and installations can be quite modular—that is, they can be built in small sizes suited to immediate needs, and quickly expanded as necessary. One recent 7-megawatt PV demonstration project, built at Carrissa Plains, Cal., by ARCO Solar, went from the drawing board to completion in less than a year. Modularity and rapid installation are critically important to utility planners, who are otherwise at risk because of the large sizes and decade-long completion times of conventional power technologies.

Solar cells are also valuable to utilities because of their dependability and low maintenance costs. The Carrissa Plains installation comes within a percent of its predicted power output, and is so free of maintenance problems that it can be run solely by computer. This is due to the inherent simplicity of PV devices, which have no moving parts.

Even the land area required for large-scale PV, contrary to popular belief, is relatively modest. If one assumes a PV array to be 15% efficient in converting sunlight to electricity, and a 50% packing fraction (twice as much land area as array area), then only 5.4 square miles are needed on a clear day to produce 1000 megawatts of electricity—which is equivalent to a large nuclear power plant. Similarly, an area only 30 miles on a side could generate 20% of total U.S. electricity capacity.

Of course, solar cells still have some problems: the sunlight-to-electricity conversion efficiencies must be greatly improved, stability must be assured for long-term operation, and existing prototype methods must be scaled up for high-volume manufacturing. Thus it is a big step from our current developmental status to producing competitive electricity, which will necessitate 15%-efficient PV modules that cost under $50 dollars per square meter and last 30 years.

We are within sight of those goals, but in order to reach them we must first convince decisionmakers in government and industry that the necessary investments are worth making.

Unfortunately, PV has so far been at the mercy of near-term economics and politics. Despite its commercial appeal, and its potential value in helping to reassert our national commitment to technological leadership, PV's priority at present is way out of line with its promise. Perhaps the best way to inspire a renewed American effort is to remind ourselves of the competitive threat: Japan has a larger commitment to PV, and Europe's is growing. If we do not make greater resources available soon for further developing this area of technology, others may dominate it—along with the potentially huge industry it will create. □

The opinions expressed in this article are those of the author and do not necessarily reflect positions of SERI, the Midwest Research Institute (which manages SERI), or the U.S. Department of Energy.

SCIENCE/SCOPE®

Improved access to a new generation of giant Intelsat satellites is planned. Intelsat VI, designed and built by Hughes Aircraft Company, is a series of five of the world's largest, most powerful commercial communications satellites. Each will have the capacity to carry 120,000 telephone calls and at least three television channels simultaneously. Making this possible is the use of very advanced digital modulation techniques. Design changes, the result of a system modification contract from the International Telecommunications Satellite Organization (INTELSAT), also will more than double the downward signal capacity of the satellite's spot beams, permitting greater coverage of North America and more connections with Europe. Called the satellite of the 21st century, each satellite in the Intelsat VI series stands 39 feet high and will use terminals as small as two feet in diameter. The first Intelsat, built by Hughes more than 20 years ago, was 4½ feet high and required Earth terminals nearly 100 feet in diameter.

An infrared viewer found potential trouble spots in a large pharmaceutical plant during a five-day survey of a 57-building complex. Hughes' Probeye® infrared viewer scanned 5,000 areas of potential trouble and pinpointed 60 hot spots, most of which were in the electrical systems and motors. For example, the Probeye unit showed a heat buildup of 120°C at three cartridge-type fuses. Also, a 75°C rise was discovered at another electrical connection. The fuse could have failed during a production run, resulting in costly downtime. The Probeye viewer sees heat the way a camera sees light, converting it instantly into an image seen through the eyepiece.

Infantry squads can maintain communications under polar conditions thanks to the Hughes AN/PRC-104 manpack radio, now the standard U.S. military field-communications system. It weighs only 14 pounds yet its lithium batteries provide enough power for voice communications at ranges of more than 1000 miles. It operates reliably at temperatures well below -50 degrees centigrade and can be used in total darkness by operators wearing the thickest mittens. Designed to meet a military specification of 2500 hours between failures, its actual record in the field far exceeds that requirement with an average of 4000 hours of fault-free operation.

U.S. Navy F/A-18 pilots will be able to see as though it were daylight while conducting low-altitude, high-speed missions at night using a Thermal Imaging Navigation Set (TINS) system developed by Hughes for McDonnell Aircraft Company. The TINS features a thermal sensor that displays a TV-like image of the terrain ahead on the pilot's head-up display. Ground objects and terrain are clearly viewed in a one-to-one real scene projection. Pilots are able to see in total darkness and through battlefield smoke and haze. TINS will be carried in a pod and mounted in a fixed, forward-looking position. Hughes will build five development systems, one of which will be used for flight testing. Delivery of these units is scheduled for fall of 1987.

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MANAGEMENT SCIENCE AMERICA:

SOFTWARE FOR MANUFACTURING

Management Science America (MSA) has a well-established reputation as one of the leading vendors of broad-based application software for mainframe computers. It is especially known for financial programs such as General Ledger and Payroll/Personnel System, which are used for accounting and human resource tasks, respectively. Over the last several years, however, the Atlanta-based firm has increasingly targeted its product development to more specialized, industry-specific markets, particularly in the manufacturing sector.

"It was clear by 1982 that the financial software market was maturing," says Douglas MacIntyre, MSA's senior vice-president of marketing, "and that we needed to strike out in other directions to stimulate growth." MSA decided to direct its initial expansion efforts to the development and acquisition of manufacturing resource planning software (known as MRP II). MRP is an umbrella term for software that offers spreadsheet-like capabilities for projecting material and cash flows, planning personnel use, projecting inventory needs, and simulating various production schedules, among other functions.

Getting into manufacturing software was a logical move for MSA for two reasons. A third of its customers were in manufacturing industries; thus, in marketing terms, the company had a ready-made base in this sector. And technical similarities between the components of MRP and financial software make these products complementary tools for a customer. For example, both the shop floor and the accounting office make use of similar databases for parts inventories and personnel work hours. These databases can be integrated with Information Expert, a program developed by MSA that acts as a translator between different software packages. Thus a clerk, for example, could process an order for parts while simultaneously checking the customer's credit (as indicated by accounts receivable) and the number of those parts currently in stock.

A series of acquisitions of several MRP firms in the early 1980s—Arista Manufacturing Systems, Computeristics, Distribution Research Associates, and RTS Limited—helped round out MSA's own MRP II product line. But the largest push into this field came with MSA's purchase of Comserv, whose sales of $27 million last year made it second only to IBM in the mainframe-based MRP market. Comserv has now been merged into MSA Advanced Manufacturing, a wholly owned subsidiary of the parent firm. With the Comserv acquisition, MSA expects to derive 40% of its 1987 revenues from manufacturing software and anticipates a large potential for growth in this sector. Over 80% of the manufacturing sites in the U.S. with more than 100 employees have not yet adopted MRP II software, according to Oliver Wight Software Research (Essex Junction, Vt.), a consulting firm; only 16% of the mainframe-based sites, where MSA currently has its biggest presence, have commercial MRP II systems.

MSA is integrating its financial programs with manufacturing software, says Douglas MacIntyre, senior VP for marketing.

Although focusing on manufacturing, MSA has taken advantage of its existing customer base and the broad utility of financial software data to enter other vertical markets as well, including government, banking, healthcare, and higher education. The firm expects to earn 40% of its sales from these fields within a few years. For example, in 1985 MSA developed a Government Expert Series, which includes a program that monitors purchasing agents so that they do not exceed budget limits. And last year, MSA formed an alliance with Technicon Data Systems to market patient-care software to large hospitals, and acquired Information Associates, a firm that offers administration programs to institutions of higher education. □ ***—Anita Micossi***

PRECISION ROBOTS:

CHIP MAKING WITH MECHANICAL HANDS

The semiconductor industry has long worried about human contamination of wafers during production; even tiny bits of dust can lead to defects, resulting in a reduced yield of chips. This problem has become even more serious in recent years; as an increasing number of circuits are packed into microchips, the threshold at which such products can tolerate foreign particles is lowered.

As a result, says Mord Wiesler, president of Precision Robots (Woburn, Mass.), "technology demands that humans be separated from wafer processing, which is only possible by increasing the automation of semiconductor manufacturing." Precision, a private company founded in 1982, claims to be the first that offered robots for cleanroom operations. The machines are used to pick up and transfer wafers from one process step to the next. By specializing in one niche, Wiesler believes that his firm has also avoided overhead

problems that can beset companies selling robots to a variety of industries; such machines often need further customization to suit particular users, adding substantially to product delivery time and cost.

Precision's customers include such leading chip producers as IBM, AT&T, Intel, Texas Instruments, Advanced Micro Devices, and National Semiconductor, as well as GaSonics (Sunnyvale, Cal.), which has incorporated Precision's robots into its own line of automation equipment, known as the Wafer Robot Automation Package.

Wiesler claims that to date the company has shipped 100 systems, priced between $40,000 and $100,000. Precision is one of the few U.S. robotics firms making a profit, says Adam Zais, an analyst with International Data Corp. (Framingham, Mass.), because it has exploited a viable niche and kept its costs down. He expects automation to become even more prevalent in semiconductor production as costly materials such as gallium arsenide are used, and as concern rises that some of the chemicals and processes used to prepare integrated circuits pose a health risk to workers. Zais cautions, however, that specialization could become a liability, since semiconductor firms have a limited capacity to absorb automation and will only make large capital investments as demand for their products warrants. Precision also faces competition in its sector from robot suppliers such as Adept Technology (San Jose, Cal.), Intellidex (Corvalis, Ore.), and Unimation (Danbury, Conn.).

Wiesler, however, does not plan to be caught short by any cooling off of his present market. By employing the same strategy of finding a wide client base and steering clear of elaborate customization, the company intends to develop niche markets in other fields. For example, systems have been sold to Los Alamos National Laboratories for handling nuclear materials, and to GM's Delco Electronics for assembling electronic components. □ —*Patricia Hittner*

FLOW SYSTEMS:

CARVING NEW NICHES WITH WATERJETS

Since its spinoff in 1974 from contract research firm Flow Industries, Flow Systems (Kent, Wash.) has captured 75% of the world market for waterjet cutting systems. The company sells its waterjets—which consist of high-pressure water pumps, fatigue- and wear-resistant fittings and tubings, and focusing cones that prevent turbulence and emit a needle-thin jet of water—to manufacturers of disposable diapers, circuit boards, paper and cardboard products, and other items for which materials must be cut without jamming up high-speed conveyor belt operations.

The company has also found a rapidly expanding niche in cutting advanced plastics and composites that replace metals in body parts and interiors of aircraft and automobiles; this segment accounted for some 25% of Flow's $22 million in revenues last year. Spending around 13% of company revenues on research and development, Flow has also adapted its waterjets for use in other growing sectors.

In 1984, for example, Flow introduced the PASER (short for "particle stream erosion"), a waterjet that drives fine abrasive particles of garnet or silicon at a pressure of about 40,000 pounds per square inch into the surface to be cut. Such particles, says Richard Brinton, Flow's vice-president of marketing, are capable of cutting through almost any material, at rates often many times faster than those of conventional hard-tipped routers and band-saws. Smooth, clean edges result, without heat damage or dust. In addition, tolerances achieved with the abrasive jet are close enough to eliminate the machining that usually takes place after materials are cut. Such factors make the abrasive jet more suitable for work on titanium, bulletproof glass, and other hard materials than competing technologies, such as ultrasonic knives, which cannot cut some materials, and laser and plasma jets, which damage many metals and composites with their extreme heat.

The abrasive jet has found customers in the aerospace and machinery manufacturing industries, particularly with contractors for the B1-B bomber, who have been requested by the Air Force to adopt new cutting technologies that would reduce labor requirements and increase finished-product quality. At Rockwell International's Tulsa plant, for example, an omnidirectional abrasive jet, controlled by a GCA Industrial Systems (Aurora, Ill.) robot, now cuts weapons bay doors, wing-sweep fairings, and other B1-B parts.

Hoping to broaden its market, Flow last year updated its product line and dropped prices by as much as 44%. Among other new products offered is a low-end ($25,000) system aimed at small manufacturers, which use it in such applications as cutting plastic seat backs for cars. These moves should appeal to small companies that are accustomed to spending the $50,000 or more previously required for complete waterjet systems.

Richard Brinton, Flow Systems' vice-president of marketing, sees aerospace firms as important customers for abrasive jets.

While waterjets now account for only a few percent of the industrial cutting tool market, they are expected to grow 25% annually over the next few years, according to William Whitlow, securities analyst at Dain Bosworth (Seattle). This prospect has stimulated some competitors to pursue Flow's market, including Ingersoll-Rand (Baxter Springs, Kans.) and start-up Jet Edge (Golden Valley, Minn.). "By improving the price performance of its products and getting into more advanced systems," says Whitlow, "Flow is in a good position to retain a large share of future markets, even if it cannot maintain its current dominance." □ —*Brad Warren*

CAD MEETS CAM

Emerging computer-aided design tools bring manufacturing sense to the drawing board

BY HERB BRODY

Throughout U.S. industry, the alarm has been raised for manufacturers to step up automation in order to make better products—and to make them more quickly and less expensively than before. Yet a great many computer tools purporting to serve these ends automate only a small subset of production. What is touted as "computer-aided design" (CAD), for example, usually boils down to computer-aided *drafting*—systems that offer dazzling graphics but few tools to improve the product that is on the drawing board. And "computer-aided manufacturing" (CAM) often amounts to using a computer to run machine tools that are not integrated with other factory operations..

Most important, CAD/CAM has so far done little to bridge the long-standing chasm between those who design products and those who make them. Advanced "solid-modeling" systems display striking, three-dimensional renderings, but usually provide no link to the shop-floor equipment that ultimately shapes parts.

Thanks to several recent developments, however, the next generation of CAD/CAM should bring computer power to bear on far more of the design and production cycle:

- Computer systems will allow engineers to design parts and assemblies by specifying readily understandable physical features.
- Product definition databases will provide complete descriptions of components and assemblies, in a form that can be transferred not only within a company but throughout an interlinked network of organizations such as parts suppliers, service providers, and distributors.
- Mechanical engineers will begin to use tools for product design that are roughly comparable to the engineering workstations now commonly used by electrical engineers to design integrated circuits and printed circuit boards.

FEATURE THIS. The conventional CAD picture is composed of lines, arcs, and other such basic elements. The computer has no built-in concept of the higher-level features that humans take for granted; the CAD model no more knows that a set of lines represents a hole, for example, than an ordinary word-processing program knows that a sequence of words constitutes a prepositional phrase.

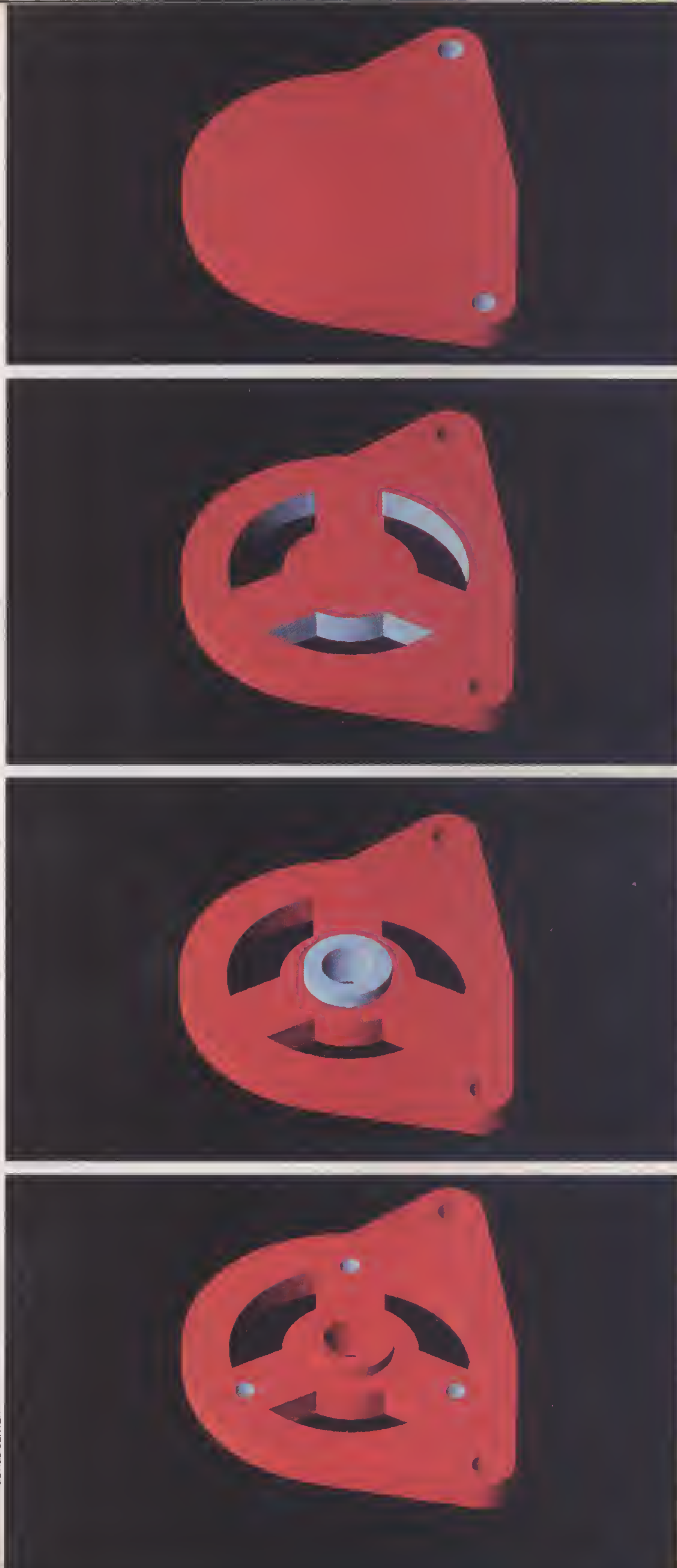
With feature technology, common entities such as holes, bevels, grooves, and notches are defined so that they can be called for and manipulated without referring to the individual geometric elements of which they are composed. Thus the designer can work more naturally. "You can create products out of the graphical equivalent of words rather than letters," explains William Rankin, manager of computer-integrated manufacturing services at Deere & Co. (Moline, Ill.).

What's more, a feature-based model can be modified far more easily than one built from more primitive geometry. Say a part has been designed with numerous bolt holes. Because the system knows what a hole is, powerful editing commands become possible. The designer can, for example, countersink all the holes with a single command, instead of finding and changing every one.

Perhaps the biggest advantage of feature technology is that it could help fill the void between design and manufacturing. A conventional engineering drawing may contain a circle with two dotted lines intersecting at its center. A person must look at the drawing (or computer screen) and deduce its meaning and then decide how to make it. But by labeling that collection of markings a "hole," the computer model provides implicit instructions on how to make it—that is, by drilling. "With a higher level of knowledge embedded in geometry, you can automatically transform a design into a manufacturing process," explains Leo Hanifin, director of the Center for Manufacturing Productivity and Technology Transfer at Rensselaer Polytechnic Institute (Troy, N.Y.).

Feature-based part descriptions can be used as well to assure that the designer does not stray beyond the bounds of what is economically producible. At Deere, for example, engineers who try to design a part with a nonstandard feature—say, a hole narrower than the smallest drill bit normally stocked—are alerted and told what alternatives are preferable from the manufacturing viewpoint. And when it comes time to design an assembly, an engineer can call for a component simply by specifying the required features, instead of looking up a part identification number and entering it. The computer offers the

Using a feature-based system, a bracket for a car alternator is sculpted on screen by calling up commonly used elements. From top: mounting holes, cooling slots, shaft support, and threaded assembly holes. Information such as size and tolerance can be specified for each feature. Besides streamlining design, feature modeling can automate process planning: e.g., a hole requires drilling.



GE R&D CENTER

designer a choice of parts fitting the description that are in inventory or that can be readily fabricated.

Such intelligence could also streamline the automated analysis of mechanical designs. A common way to predict how a structure will perform under loads, for example, involves mathematically dividing a computer model of it into tiny pieces, called finite elements. Using more elements increases the accuracy of the analysis but also prolongs the calculation. With a feature-based model, the finite-element software would know not to waste computation time on hollow regions of the model, according to Peter Wilson of General Electric's R&D Center (Schenectady, N.Y.), one of the earliest proponents of feature technology.

Ultimately, a feature model should provide sufficient information to drive the numerically controlled (NC) tools such as milling machines, lathes, and drill presses that make the part. Deere has already achieved such "generative NC" with a particular family of parts—sprocket hubs. The computer asks the designer a series of questions about the desired shape of the hub, and then responds by displaying a picture, compiling a process plan (a detailed description of which tools to use and the optimum sequence of operations), and writing the NC program. Deere is compiling a dictionary of common features to extend generative NC beyond sprocket hubs to cover sheet-metal parts. Rankin says that even though Deere is not yet ready to use feature technology on complex parts, its system is widely applicable. Deere uses 17,000 sheet-metal parts, he says, and "85% of them are simple. Rather than hold them hostage until we have the technology to handle complex ones, we're automating the mundane."

Deere devised its own feature-based system. But similar capabilities are becoming available off the shelf. For example, Automation Technology Products (ATP), a start-up in Campbell, Cal., is working with machine tool maker Ingersoll Milling Machine (Rockford, Ill.) to develop a CAD/CAM system that drastically reduces the need for human interpretation of engineering drawings. The system will cut in half the time needed to set up production for a new part, asserts Richard V. Houser, director of CAD/CAM plan-


BILL O'CONNELL

Top: "Igor" system will both serve and monitor Sikorsky's 2600 engineers, says CAD/CAM chief Joe Piteo. Bottom: Deere's Rankin calls feature modeling the "graphical equivalent of words rather than letters."

ning and development at Ingersoll.

Feature technology is still in its infancy. Even leading-edge companies such as Deere and Ingersoll are "just getting their feet wet," says Larry Patrick, marketing director at Computer-Aided Manufacturing International, a research cooperative based in Arlington, Tex. "There are probably 1000 features" that should be defined for modeling, says Patrick, and ATP's current system accounts for only a few dozen.

One problem is that the features that matter most from a design standpoint are not necessarily the most crucial in figuring out how to make the part. Typically, a designer cares about the material that will exist in the finished part—its shape and dimensions determine its function. But what's important on the shop floor is the material that must be removed—this is what defines the machining process.

One way to provide the link would be with software that could examine a computer model and identify features, much as human process planners do now. That way, engineers could design in terms they're comfortable with and leave it to the computer to infer whatever features may be important to the process planners down the line. Moreover, a feature recognizer could breathe new life into the millions of engineering drawings already on file, whether on paper or in conventional CAD systems. It's analogous to optical character recognition scanners, which recognize the shapes of letters and numerals, thereby converting hard copy into standard digital code that can be stored and manipulated electronically. So far, however, feature recognition is still a research topic. Groups are working on the problem at several institutions, including the University of Michigan, Arizona State, and Brigham Young in the U.S., the University of Aachen in West Germany, and Institute Nationale Polytechnique in Grenoble, France.

Such feature recognition would unburden the design engineers, leaving them free to think purely in terms of function and performance. But some contend that this approach would merely reinforce the barrier that already hampers communication between engineering and manufacturing. Designers, by this argument, *ought* to be sensitive to manufacturing constraints.

A MATTER OF DEFINITION. Features are really but one aspect of a larger issue affecting CAD/CAM: the need for complete, unambiguous information about a part or product. Ideally, such "product definition" data could be drawn upon by any person or machine involved in designing, engineering, manufacturing, servicing, or replacing a part. "The goal is to functionally replace the engineering drawing as the way to pass information," explains Robert A. Carringer of International TechneGroup (Cincinnati), who initiated the Air Force's pioneering Product Definition Data Interface (PDDI) program. Right now, says Carringer, many companies use computer-aided drafting as well as numerically controlled machine tools—but information still travels between these two computer-based operations in the form of drawings on paper.

The main obstacle has been the lack of a standard way to encode all the necessary manufacturing information on a traditional CAD system. There is little trouble transmitting the basic content of the drawing in electronic form: most CAD systems use some version of the Initial

Graphics Exchange Standard (IGES), established by the National Bureau of Standards (NBS). But to make a part, it's necessary to know considerably more about it than the rudimentary geometry carried via IGES.

With PDDI, a much richer base of information can be transmitted between different design and manufacturing systems. In addition to a part's geometry and features, PDDI provides a format for noting such attributes as material, color, surface finish, expected lifetime, and maintenance requirements. The system also provides a way to transmit the critical data on a variety of manufacturing tolerances—dimensional, concentricity, flatness, perpendicularity, and others. Such tolerance data, not contained in IGES descriptions, are essential for producing a part because they can determine what process or machine to use. If a hole's diameter is specified with a very tight tolerance, for example, then it must be reamed as well as drilled.

MCAE is to conventional CAD what a spreadsheet is to a word processor.

A part description encoded via PDDI contains information relevant to a variety of professionals, from manufacturing engineers to quality control specialists and NC tool programmers, according to Gerald Shumaker, technical manager of the Air Force's computer-integrated manufacturing (CIM) branch at Wright-Patterson Air Force Base (Dayton, Ohio). The computer can display the model of a part and answer such questions as: Where are all the 45° chamfers? How many holes are toleranced tightly enough to require reaming? Are there any grooves on the top surface?

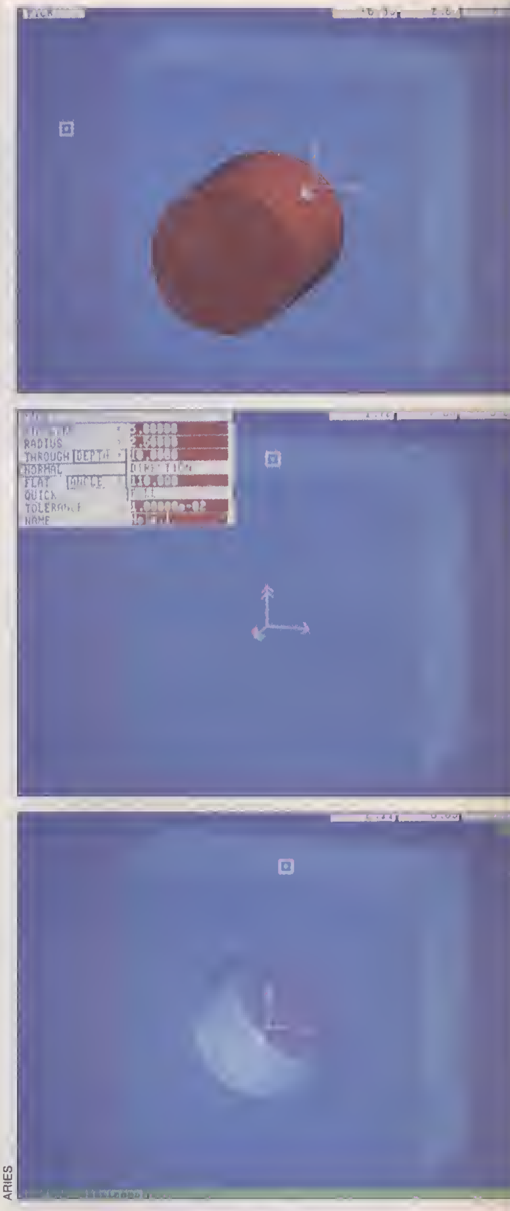
In a "walk-through" of PDDI planned for this spring or summer, Air Force contractor McDonnell Douglas Aircraft (St. Louis) will design several aircraft components on its in-house CAD system, code the data into a PDDI file, and electronically transmit the information to subcontractor Vought Aero Products (Dallas). There, computers will automatically generate the NC program, and machine tools will cut the part.

The need for information doesn't end when a product leaves the factory, though. Throughout its life cycle it will need maintenance, repair, and possibly replacement. Thus the Air Force is following up PDDI with an effort that aims to take the idea of product definition a step further. The goal of the new Geometric Modeling Application Program (GMAP) is to develop a product description sufficient for the entire life cycle, says Richard Lopatka, manager of computer-integrated manufacturing technology at GMAP contractor Pratt & Whitney (Hartford). In the first demonstration of GMAP, Pratt & Whitney will design jet-engine turbine blades and the disk that the blades sit in; the data generated during design will be transmitted to the Air Force blade inspection system in San Antonio, which will use the data as a reference when examining the actual manufactured blades. Without such a setup, much of the information that already exists in a CAD model must be manually reentered into the inspection system.

The military has pioneered work on product definition, but civilian industry stands to benefit from the fallout. The IGES organization, composed of representatives from NBS and some 200 companies, is working to establish a Product Data Exchange Standard (PDES), due out in draft form this spring. Like PDDI, the new standard will accommodate feature-based descriptions, tolerance information, and other data. But unlike the Air Force–sponsored approaches, PDES "won't be biased toward aerospace," says Bradford Smith at NBS, chairman of the IGES organization. "You can use it to make a lawn mower or just about anything else."

PDES proponents say the standard will usher in the next phase of factory automation, in which product information is electronically distributed not just to the machines and computers at the manufacturing company, but also to the network of other companies associated with the product (parts suppliers, machine vendors, customers, and so on). Without the evolution to such interorganizational CIM, "automation is going to grind to a halt," warns Thurber J. Moffett of Northrop (Norwalk, Cal.), PDES project manager.

ENGINEERING TOOLS. While feature modeling and product definition can make manufacturing more efficient, another trend in CAD/CAM promises to improve the design of the products themselves. That function is being served by a new breed of systems that perform what has recently come to be known as mechanical computer-aided engineering, or MCAE. The concept is similar to electrical CAE, which has been growing tremendously in popularity for the past five years; electrical engineers use sophisticated computer workstations to design, optimize, and test ICs and printed circuit boards before committing to hardware.



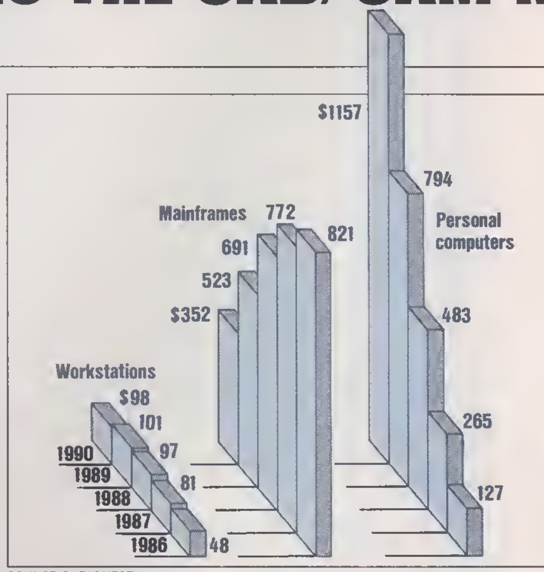
ARIES

In conventional solid modeling, making a hole requires the engineer to create an appropriately sized cylinder, then subtract it from the workpiece (top). With a feature-based system (middle), the same result can be attained by calling explicitly for a hole and specifying such parameters as its diameter and whether it is to go all the way through.

Some pieces of MCAE have been available for years. Companies such as Structural Dynamics Research Corp. (Milford, Ohio), Evans & Sutherland (Salt Lake City), and PDA Engineering (Santa Ana, Cal.) offer solid-modeling systems along with software to perform sophisticated analysis using finite elements and other methods. These tools are used mainly by specialists in structural analysis, who verify a design after it has been largely com-

MECHANICAL ENGINEERING ENTERS THE CAD/CAM MARKET

The largest slice of the $5.6 billion CAD/CAM market last year was held by the $3.3 billion in hardware and software sales going for mechanical design, drafting, and manufacturing applications, according to Dataquest (San Jose, Cal.). Other segments included electronic design and engineering ($1.3 billion), and programs for architecture, engineering, and construction ($900 million). A specialized market devoted to mechanical computer-aided engineering (MCAE) has recently opened up that promises to be a source of rapid growth within CAD/CAM as a whole.



SOURCE: DATAQUEST

In contrast to mechanical CAD, analytical tools provided by MCAE systems enable engineers to conceptualize the design of mechanical parts, optimize a design, and undertake analytical functions, such as the calculation of physical properties and stress. Industry observers have yet to agree on what specific products MCAE encompasses, but Dataquest, which takes the broadest view of the market, estimates that it will grow from $996 million in 1986 to $1.6 billion in 1990.

Current market leaders in MCAE are the same companies dominating mechanical CAD/CAM generally: IBM (Armonk, N.Y.), with a market share of 27.7%, and Computervision (Bedford, Mass.), with 12.2%. However, mechanical CAE is shaping up as a market in which smaller players with advanced, proprietary technology may be able to hold their own against the industry giants. Typical of such specialized firms are a group of established engineering software companies that offer advanced design, modeling, and analysis programs for MCAE applications. They include Structural Dynamics Research Corp. (SDRC) in Milford, Ohio, and MacNeal-Schwendler (Los Angeles), each with 10% of the market, along with Swanson Analysis Systems (Houston, Pa.) and PDA Engineering (Santa Ana, Cal.). Aries Technology (Lowell, Mass.), Cognition (Billerica, Mass.), Iconnex (Pittsburgh), and Cadetron (Atlanta) are among the start-up companies that have entered this field.

The MCAE market is diversifying in two directions. The first exploits advanced MCAE systems, used primarily in the aerospace and automotive industries, that are built around solid-modeling software and 32-bit technical workstations, according to Wayne McClelland, SDRC's director of product planning. Solid-modeling programs allow engineers to create and analyze models that realistically represent the entire object being designed; technical workstations, says McClelland, have the computing power needed to manipulate a model's complex database and transmit it for use at other points in the manufacturing process—say, in the generation of numerically controlled machine tool paths.

Falling prices of workstations from such vendors as Apollo Computer (Chelmsford, Mass.), Sun Microsystems (Mountain View, Cal.), and Digital Equipment (Maynard, Mass.) have made advanced MCAE tools more widely available. "Multiuser systems, including hardware and software, that used to cost over $100,000 per seat are now available for $40,000 per seat," says McClelland. "The MCAE market will really take off when prices become low enough so that it is cost-effective to put these tools on the desks of occasional users."

Other firms, however, believe that such users can already turn to less sophisticated but easier-to-use tools that can be run on PCs. "Most mechanical engineers do not require solid-modeling capabilities," says Bruce DaCosta, president of Iconnex, "because design tasks take up only 10% of their time." What most engineers really need, he believes, is to automate the initial sketching and drawing performed in routine work. Instead of paper, pencils, and calculators, the engineer can use low-cost, spreadsheet-like software incorporating equations found in engineering handbooks, documentation and networking capabilities, and simple graphics. The models created by such software can be passed on to solid-modeling systems for further detailing and to CAD terminals for final drafting.

Individual components of some of these systems are already available in such forms as equation-solving and word-processing software. Companies like Iconnex and Cognition have adapted these tools for MCAE use, without incurring the high costs of developing more advanced design systems. As the market for those systems becomes saturated, low-end applications are likely to provide the best opportunities for growth, says Bruce Jenkins, analyst at Daratech (Cambridge, Mass.). "Indeed, the situation is just ripe for PC software publishers to begin moving into the MCAE field." □ —***Elizabeth J. Heichler***

> ***"With MCAE tools, engineers can see the effects of changes in one part of a mechanical design automatically reflected in the rest of the system. This saves time and greatly improves accuracy when making design changes."***
> *Bruce DaCosta, President, Iconnex*

pleted. The new MCAE systems, introduced in the past year or so by a number of start-up companies, introduce automation earlier in the design process. Engineers can play "what if" games—examining, for example, how substituting aluminum for steel will affect the dimensions of a load-bearing structure.

"MCAE is to conventional CAD what an electronic spreadsheet is to a word processor," says Philippe Villers, founder and president of Cognition (Billerica, Mass.). With a word processor, he explains, changing one number in a column has no effect on the other nunbers. A spreadsheet, on the other hand, is programmed to reflect the intricate web of relationships among variables: a change in one number results in automatic adjustment of all the others.

Villers, who previously founded CAD pioneer Computervision and robot systems integrator Automatix, maintains that MCAE systems like Cognition's let mechanical engineers use the powerful analytical techniques that they learned in school. In the rush to meet production deadlines, he says, engineers spend far too little time evaluating alternative designs to accomplish the specified goal. This dearth of early-stage optimization, he contends, means that products typically are built from the "best design in a field of one rather than the best in a field of many." Moreover, he says, engineers tend to design parts bigger and stronger than turns out to be necessary, in order to cover for the lack of analysis. Such overdesign can hike manufacturing costs significantly.

The new MCAE systems offer differing capabilities. Cognition's Mechanical Advantage automates the earliest stages of design, when, according to Villers, 50–80% of a product's manufacturing costs are determined. It's sort of an electronic back-of-the-envelope. The user sketches shapes on the screen, constraining the geometry to reflect the engineering intent: circles can be stipulated to be concentric, surfaces parallel, and so on. With such a set of linkages built into the model, any modifications of one part of the sketch trigger the appropriate alterations everywhere else; if a mounting hole on one part is moved, for example, the mating hole in the piece it's attached to will shift accordingly. Commonly used engineering equations and data can be called from a manual in the system's memory and applied to the design problem at hand.

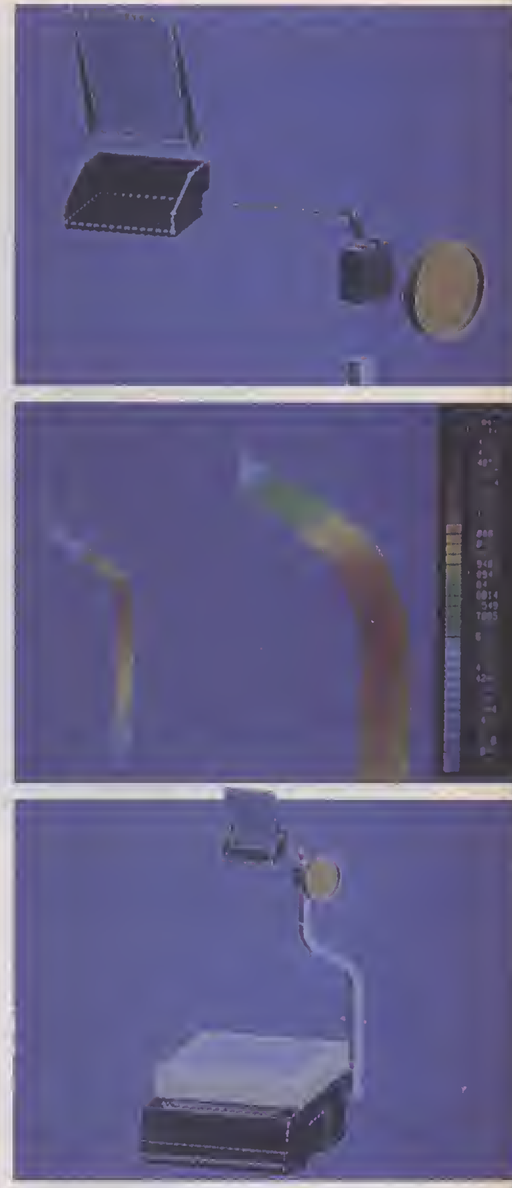
While the Cognition system addresses the needs of the individual designer doing preliminary sketches and calculations, Aries Technology (Lowell, Mass.) takes on a larger swath of the design/engineering/manufacturing cycle. Cognition's graphics are limited to two-dimensional sketching, but Aries' ConceptStation provides a solid modeler. Thus engineers can easily see what a part will look like early in the design process. Components designed with the system can be stored in a "parts library," which can later be tapped to assemble a product on screen. The system provides finite-element analysis to verify that the completed structure does what it is supposed to.

Neither Cognition nor Aries provides a direct link to the shop floor; the output of either system must be passed to conventional CAD/CAM equipment for detailed drafting and NC tool programming. Partly because of that limitation, MCAE is not catching on rapidly. "There's nothing in principle wrong with creating another acronym," says Gene DuVol, corporate manager of manufacturing planning at NCR (Dayton, Ohio). "My fear is that these systems concentrate too much on up-front design and engineering analysis, and are not enough concerned with downstream manufacturing."

ICAD claims that its system reduces routine product design almost to a clerical task.

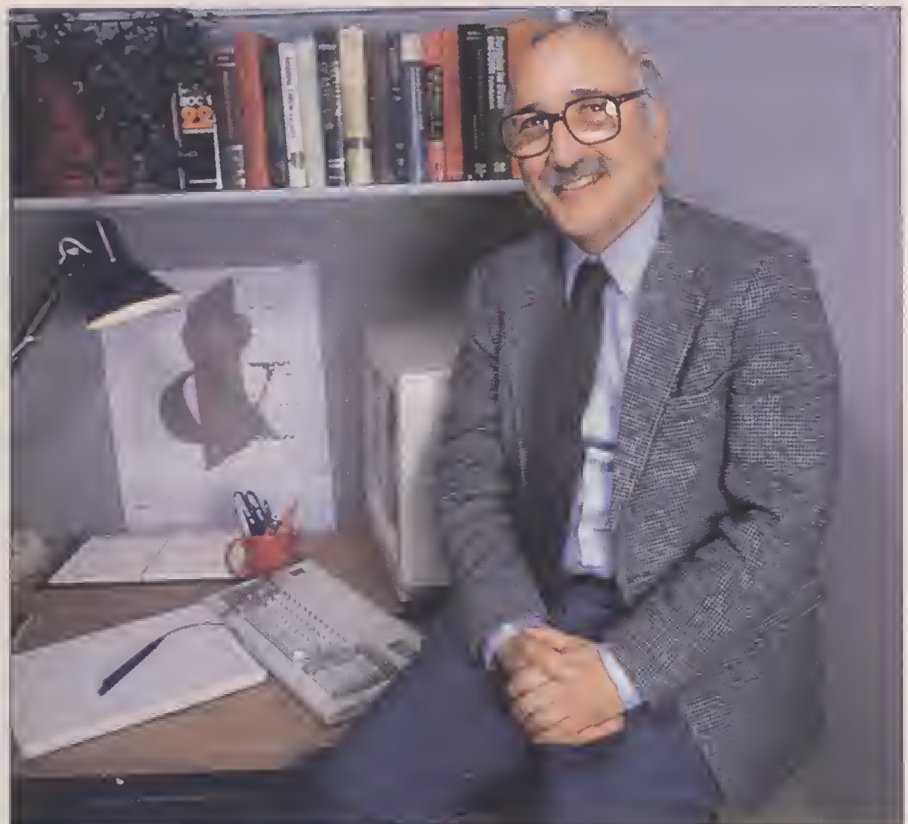
Cognition, however, is readying software that will do more to put the designer in touch with the manufacturer's problems. This program, due out in the fall, incorporates an expert system that estimates how much it will cost to manufacture the product being designed. Design choices are reflected in the bottom line. In sheet-metal fabrication, for example, each additional bend and hole adds to the machine setup time and hence to the overall production cost. The expert system also flags the designer if a part's specifications violate the restrictions of the process that will be used to make it. The walls of a die-cast part, for example, must exceed a minimum thickness that varies with the material. Cognition recently began working with University of Rhode Island professor Geoffrey Boothroyd, who has pioneered the field of "design for assembly."

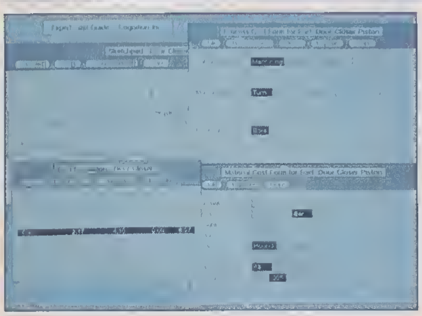
Mechanical engineers spend much of their time designing products that are slight variations on others in a family. ICAD (Cambridge, Mass.) aims to automate this routine engineering. The key, says company president Lawrence Rosenfeld, is to capture "design intent," or the reasons that parts and structures must be a certain way. With the ICAD system, an engineer creates a design database by entering various constraints that a class of products must obey. For example, a structure may need a support member for every six inches of width. Or a part's mounting holes may have to be placed one inch from the edge, and its total weight may have to be under 100 pounds.



Aries' ConceptStation lets engineers design with components stored in a "parts library." Top: optics and focusing knob of an overhead projector. Middle: support bar, showing stress analysis. Bottom: these parts are "snapped together" with a base structure to finish the projector.

Once such a database has been created, designing a new version of a product becomes more a clerical than an engineering task. It's necessary only to enter information on the desired performance. Based on these specifications and general design rules, the ICAD system designs the product "down to the last nut and bolt," ac-





Philippe Villers helped launch the CAD business by founding Computervision in 1969. His new company, Cognition, aims to automate the early, "back-of-the-envelope" stage of design. For example, Cognition is developing an expert system (bottom) that estimates the cost of manufacturing a given design.

cording to Rosenfeld. In one of its first uses, the system took less than an hour to design a large heat exchanger containing over 10,000 parts; without ICAD, says Rosenfeld, the job would typically take 80–300 man-hours.

The finished design produced by the ICAD system contains enough information to satisfy many downstream needs, according to Rosenfeld. In addition to producing a detailed 3-D drawing, it can generate a list of required materials (automatically broken down by subassembly), a process plan, and NC part programs. In performing these tasks, the ICAD system consults a separate database—compiled by manufacturing engineers familiar with the factories that might be used to make a product—containing the actual capabilities of specific plants, such as what machines are in operation and what their limits are.

ICAD's system essentially serves as an intelligent hub interlinking design, engineering, and manufacturing information. A similar approach is being pursued independently at Sikorsky Aircraft, the Stratford, Conn., helicopter manufacturer. Sikorsky, a division of United Technologies, is devising a computer system to tie all of the company's 2600 engineers into a common database. In most companies, by contrast, engineers work in relative isolation, says Joe Piteo, Sikorsky's chief of CAD/CAM. The information sharing made possible by such massive interconnection should increase engineering productivity fourfold, Piteo predicts.

Slated for operation by midyear, the system—named Igor, in memory of founder Igor Sikorsky—will connect to MCAE as well as conventional CAD terminals. An engineer might, for example, use a Cognition station to sketch out the design of a new cockpit. And because Igor will be programmed with the basics of cockpit design, it could alert the engineer to work that a Sikorsky group in another city is doing on flat-panel displays—devices that the designer might want to substitute for bulky cathode-ray tubes. Igor will also keep tabs on the manufacturing technology available throughout the company, warning engineers if a design would cost too much to produce.

Piteo hopes that by providing ready access to relevant information that might otherwise be buried in separate parts of the company, Igor will approach the omniscience of the founder. "Igor will be the glue that binds all the dinky pieces of CAD/CAM together," he says. In addition to supplying information, Igor will monitor the engineers' work. It will know, for example, who has contributed to what projects. If a component fails in the field, Igor will transmit an on-screen message to everyone involved, so that they might rethink the way it was designed or produced.

Monitoring can take other forms as well, says Piteo. Over time, Igor will compile enough data to calculate how many hours it takes on average to design a new part. An engineer who lingers too long on the job might be reported to a supervisor. Piteo concedes that such computer nosiness might make a lot of people nervous, but hopes that Igor will be so helpful that engineers will not much resent its ability to check up on them. Still, he says, Sikorsky management is aware of the Big Brother possibilities, and has formed a steering committee to keep Igor clear of abuse as it is fully implemented over the next three years. Igor-like systems will eventually be installed at other United Technologies divisions too, according to Piteo.

Systems such as Igor and ICAD highlight the evolution of CAD/CAM from its electronic drafting board origins into a technology for coordinating the entire manufacturing enterprise. But in order for this wider application to produce benefits, users will have to do more than plug the systems in. "The only way to get improved quality and design from CAD/CAM," says NCR's DuVol, "is to change the process itself."

One of the main advantages of solid modeling, for example, is that it creates an image that can be interpreted far more easily than a two-dimensional blueprint can. Thus a solid model offers the chance to solicit suggestions for changes from a variety of sources, such as manufacturing engineers, marketing specialists, and customers. The key is to apply their ideas early in a product's development, when designs can be modified painlessly. Ultimately, says Du Vol, "the power doesn't lie in the tools, but in the skills of the people and in how they work together." □

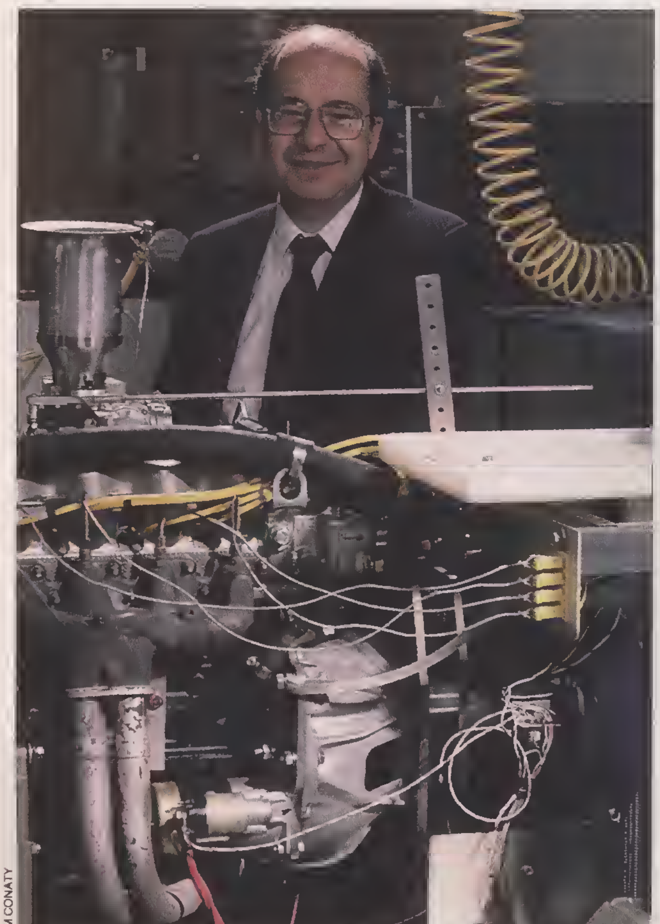
Herb Brody is a senior editor of HIGH TECHNOLOGY.

For further information see **RESOURCES**, *p. 61.*

AUTO ENGINES COME CLEAN

Impending emission limits in Europe are giving rise to techniques for burning fuel more thoroughly

BY ERNEST RAIA



JIM CONATY

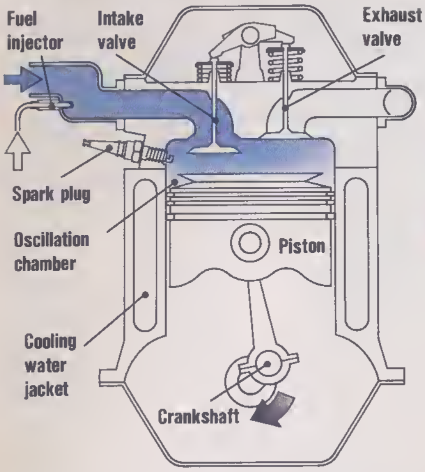
Michael Ward of Combustion Electromagnetics: putting more energy into ignition.

Automotive air pollution is getting attention once again among carmakers, this time because of a strict clampdown scheduled to take effect in Europe beginning next year. While manufacturers in the U.S.—who have lived with tough emission standards since 1981—continue to rely on after-the-fact catalytic converters for pollution control, European companies are exploring technologies that reduce emissions largely at their source: within the engine. This strategy is lending support to a number of small, independent companies specializing in combustion research. Notable technologies under development by such companies include electromagnetic ignition by Combustion Electromagnetics (Arlington, Mass.), sound wave–aided combustion by Sonex Research (Annapolis, Md.), and a unique fuel injection system by Orbital Engine (Perth, Australia). In each approach, the automobile's traditional reciprocating piston engine is modified to burn fuel more completely and at lower temperatures, and thus to reduce polluting emissions considerably.

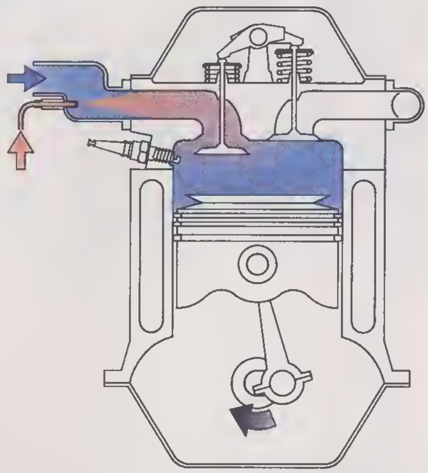
In a perfect engine, the only byproducts would be water vapor and carbon dioxide (harmful only if one considers the global greenhouse effect). In actual operation, however, traces of fuel do not fully burn, leaving hydrocarbons and carbon monoxide. Also, excessive heat causes nitrogen in the air to combine

How Sonex controls combustion

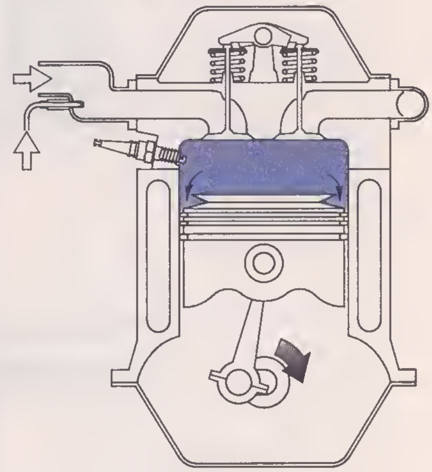
1. As valve opens at start of intake stroke, pure air enters cylinder.



2. Fuel follows, creating stratified charge for fast, cool burn that inhibits oxides of nitrogen from forming.



3. During compression, air and some fuel enters oscillation chamber.



with oxygen, forming oxides of nitrogen (commonly called NO_x). These are the three pollutants covered in auto emission standards in the U.S. and Europe.

Thus far in the United States, pollution control has centered primarily on catalytic converters—canister-like chambers attached to the exhaust system. As exhaust gases flow through a converter, they come into contact with the catalyst element (platinum, palladium, or rhodium), which in an oxidizing converter stimulates oxidation of CO and hydrocarbons, or, in a reduction type, reduces oxides of nitrogen. Since tougher U.S. standards took effect, in 1981—cutting allowable CO and NO_x emissions in half and holding hydrocarbons to 0.41 gram per mile— American cars have been equipped with "three-way" converters that abate all three pollutants while adding an estimated $500 to $1000 to the price of a car.

Three-way converters are effective only if the ratio of gasoline to air entering the engine is kept at a precise level—otherwise the device will be overloaded with either the carbon or nitrogen compounds. Thus they are equipped with "lambda" sensors that measure oxygen content, feeding the data to the engine control computer so it can maintain the balance of fuel and air. This requires electronic fuel injection and correspondingly sophisticated computer control. Such complexity makes three-way converters prone to early failure, says Robert W. Crandall, senior fellow at the Brookings Institution (Washington, D.C.) and coauthor of its published study "Regulating the Automobile." Also, the catalyst may be contaminated by gasoline additives, especially lead. In any case, says Crandall, a bad converter doesn't affect a car's performance, so "there's no incentive for the consumer to keep it in repair."

In addition to those shortcomings, the fuel/air mixture required by three-way converters is relatively "rich"—containing a high proportion of fuel for a given volume of air. This means cars with three-way converters sacrifice some fuel economy, a trade-off that's generally unacceptable in Europe, where higher fuel prices make economy a more sensitive issue than in the U.S.

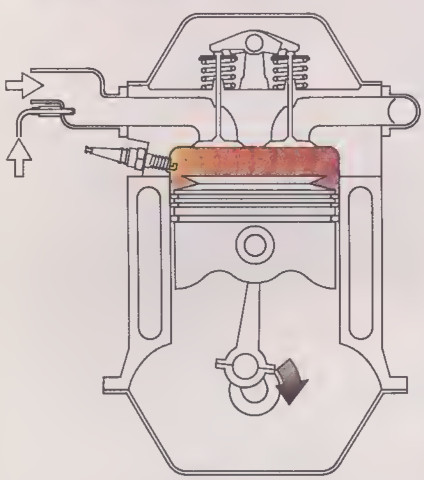
Thus European carmakers have been working for several years to avoid the need for three-way catalytic converters by developing "lean-burn" engines that will meet the emission restrictions taking effect in European Community countries beginning in 1988. "Lean-burn" refers to the ratio of air to gasoline that's burned in the combustion chamber (the space between the head of the piston and the top of the cylinder, where the spark plug electrodes are located and combustion begins). In an ordinary engine, about 14 units of air are needed to supply enough oxygen for complete combustion of one unit of fuel. Lean-burn engines are specially designed to use a higher proportion of air; this improves fuel economy, since less gasoline enters each combustion chamber. Also, the leaner charges burn cooler, reducing NO_x emissions. To get NO_x to allowable limits, engines must run on a ratio of 22:1. In many cases, the lean-burn engines under development in Europe would still require an oxidizing catalytic converter to remove hydrocarbons and CO. This solution is generally considered acceptable by European automakers, since an oxidizing converter is much simpler than a three-way type.

Because they are slightly less stringent than emission restrictions in the U.S., the pending European standards make it easier to control exhaust gases through lean-burn technology, and so the car companies are more willing than their U.S. counterparts to try this approach. Ford of Europe, for example, recently developed 2.4-liter and 2.9-liter V-6 engines that control emissions with lean burn. But in keeping with the general tendency among European carmakers, Ford is keeping details of its engine developments under wraps; since standards are not finalized and all countries haven't agreed to the same set of restrictions, the carmakers fear that a show of technology readiness may inspire governments to set tighter standards than those already proposed.

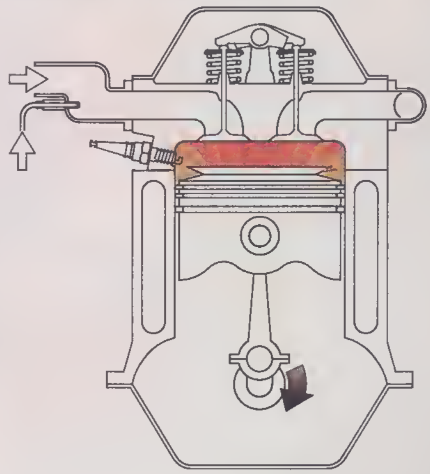
What's clear is that these companies are interested in the technology under development by the small independents. Both Sonex and Combustion Electromagnetics are negotiating to license their technologies to a number of undisclosed European automakers, and Ford's European operation is testing the Sonex approach. Meanwhile, Orbital manager Ken Johnsen says his company is negotiating with eight European carmakers.

The main problem with lean burn is that combustion is slower because fuel molecules are more widely spaced. In fact, at 22:1 it is difficult to get the flame front moving at all, and cylinders often fail to ignite. The common remedy is to design components that induce turbulence inside the combustion chamber, helping to spread the flame (HIGH TECH-

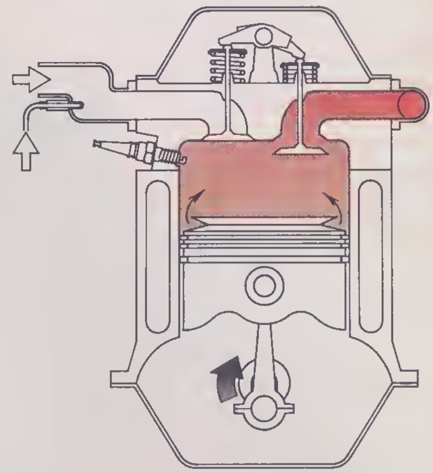
4. Combustion shock wave reaches oscillation chamber . . .



5. . . . stimulating self-pumping for complete combustion of hydrocarbons and CO.



6. During exhaust, fuel traces burn in oscillation chamber.



ILLUSTRATIONS BY MARK ALSOP

NOLOGY, June 1986, p. 12). But this has a drawback: turbulence brings the flame front into contact with relatively cool surfaces like cylinder walls, quenching it and thereby increasing hydrocarbon emissions due to incomplete combustion. Quenching also lowers efficiency, since some of the fuel's energy is absorbed by the engine cooling system through the cylinder wall and then dissipated.

ENHANCED IGNITION. The inherent problem of incomplete combustion in lean fuel/air mixtures can be overcome if burning is speeded up, according to John B. Heywood, professor of mechanical engineering and director of the Sloan Automotive Laboratory at MIT. For example, more ignition energy can be used to start combustion, an approach under development by Lucas Industries (Birmingham, England). Lucas is developing plasma jet ignition systems that, in properly designed engines, meet pending emission standards without a catalyst, says Jack R. Fryer, product technology group director. Under investigation by other companies as well, plasma jets replace the spark plug, using a separate electrical power source to convert the spark into a high-energy plume, or "torch tip," that shoots into the combustion chamber. A nagging problem with plasma jets, however is durability; their high output corrodes electrodes, reducing their lifespan.

Meanwhile, Combustion Electromagnetics has abandoned work on plasma jets in favor of its recently developed electromagnetic ignition. The new approach is much simpler, claims company president Michael Ward, yet it achieves the same goal of putting more energy into ignition. Whereas other methods essentially mandate engine redesign to accommodate the added equipment, Combustion Electromagnetics' concept uses components that can be retrofitted onto existing engines. The system, which delivers an intense spark followed by a sustained high electromagnetic field at the spark plug to help launch the flame, has three main components: an ignition driver (the equivalent of the conventional ignition coil, which induces a high-voltage spark), an ignition controller that "tunes" the spark to the desired characteristics; and a specially designed spark plug. Ward says that the system burns the 22:1 mixture necessary to control NO_x, but that it would require an oxidizing catalytic converter for the other pollutants.

Combustion Electromagnetics' new system is the result of research in electromagnetic stimulation dating from the company's founding in 1977. It's work is based on the principle that a plasma (ionized gas) forms at the flame front as fuel molecules enter the early stages of combustion. In electromagnetic stimulation, this plasma energy is harnessed by immersing the combustion chamber in an electromagnetic field, which excites the plasma further so that combustion occurs faster. "The idea is to get a cooler flame to behave as a hot one," says Ward. In addition to negotiating with several European manufacturers, Combustion Electromagnetics is operating under a two-year contract to develop an engine for the U.S. Army Tank-Automotive Command.

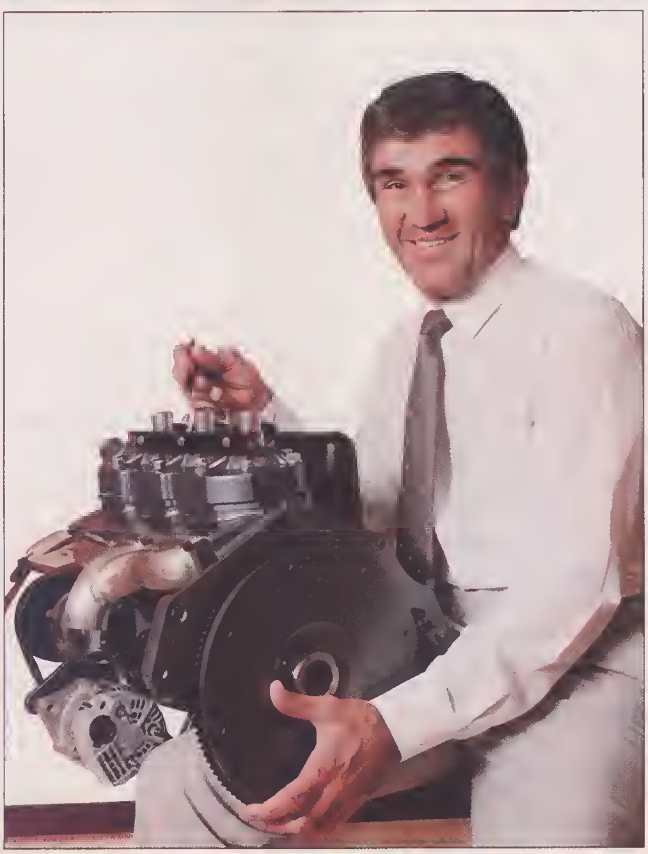
SOUND WAVES. Instead of pursuing better ignition systems, Sonex Research is achieving lean burn by changing the physical characteristics of an engine's combustion chambers. So far, the concept has the support of the British engine component supplier AE of Rugby, which has signed on as a development partner with Sonex. Also, the concept is currently being tested by Ford's European operation, and talks are under way to license the technology to other European companies. Earlier, tests by the independent International Automotive Testing Laboratory (Telford, Pa.) found that a Sonex engine in a British Ford Escort produced emission levels 25% to 30% below the pending European standards. And at about 56 mph, it showed a nearly 30% improvement in fuel economy.

The Sonex approach begins with a dual intake manifold: whereas each cylinder in a conventional manifold has one tube or passageway to deliver air and fuel, each Sonex cylinder has two. One delivers fresh air only, the other a mixture of gasoline and air. They are configured so that the air reaches the cylinder first and is sucked in before the mixture. This creates a "stratified charge" in which a higher concentration of fuel is near the inlet at the top of the chamber, which, in turn, is near the spark plug. Relatively few fuel molecules reach the bottom of the chamber, around the top of the piston. This denser concentration of fuel near the spark plug ensures that the flame spreads quickly and thoroughly.

Sonex next alters the top of the piston, forming a cavity around its circumference, just below its top. This cavity fills with the leanest portion of the stratified

WALTER CALLAHAN

Above: Modifying the combustion chamber to raise compression, says Sonex's Andrew Pouring, results in cleaner emissions and better fuel economy.



Right: Ralph Sarich, Orbital's managing director, demonstrates the weight savings possible through two-stroke engine design.

charge. Here the air and sparse fuel of the "end gas" are sheltered from the compressing force of the shock wave that occurs as the flame front spreads outward from the spark plug. In conventional engines, this compression causes the phenomenon known as "knock" when it drives the temperature of the end gas so high that the fuel ignites spontaneously, causing erratic combustion that creates damaging, audible shock waves. By sheltering the end gas, the Sonex piston prevents knock, enabling the engine to operate with higher compression ratios than conventional designs and to achieve better fuel economy as well.

To keep hydrocarbon and carbon monoxide emissions down, Sonex assures that the end gas in the piston cavity gets burned by shaping the cavity to produce a self-pumping action to push gas into the combustion chamber. The oscillations, or sound waves, are created by "tuning" the cavity's shape and volume to cause the gas inside to resonate when pressure is applied by the shock waves in the combustion chamber.

But that alone wouldn't be enough, because the fuel molecules coming from the oscillation chamber are so sparse that they still might burn only partway, leaving hydrocarbons. The remedy to this

problem is built in: as the shock waves from combustion continue to stimulate oscillations in the cavity, the temperature of the constantly moving molecules rises to about 1000° F, at which point the fuel molecules prereact, or change to a chemical state in which they will burn more readily once pumped into the flame.

Another benefit built into the Sonex design, claims president and cofounder Andrew Pouring, is its ability to clean up traces of unburned gas that lodge in the crevices around piston rings (metal bands around the side of a piston—below Sonex's oscillation chamber—that seal the gap between piston and cylinder wall). Ordinarily, when the exhaust valve opens after combustion, pressure in the cylinder drops; then unburned fuel pumps out of the ring crevices and escapes in the exhaust. But Pouring claims that in a Sonex engine it enters the oscillation chamber, where enough oxygen and heat remain to fully burn the gas.

In May or June, Ford will road-test Escorts equipped with an Orbital 1.2-liter four-cylinder engine. Ford's aim is to meet U.S. NO_x standards without a converter, using an oxidizing catalyst only for CO and hydrocarbons. The agreement stipulates that if the tests are successful, the companies will have two months to hammer out a nonexclusive license for Ford to build, use, and sell Orbital engines. General Motors has a similar development agreement with Oribtal.

Orbital's approach was developed to improve combustion in standard automobile motors—four-stroke engines that require four piston movements, or strokes, to complete the combustion cycle: intake, compression, combustion, and exhaust. But the concept may also make two-stroke engines suitable for cars. According to the journal *Ward's Engine Update*, major U.S. automakers are investigating two-stroke engines because their relative simplicity makes them

In the U.S., the Environmental Protection Agency is considering new regulations, such as 100,000-mile warranties on emission equipment, that may force carmakers to consider cleaner-burning engines.

lighter, more reliable, easier to manufacture, and less costly than conventional four-stroke designs. Instead of moving valves for fuel/air intake and waste exhaust, two-stroke engines have intake and exhaust ports in the cylinder wall that are opened as the piston is driven downward during combustion, sliding past them. As the piston rises during the compression stroke, it covers the ports back up.

Besides minimizing emission problems, the Sonex design opens the door to dual-fuel engines—superefficient hybrids that can run on both gasoline and diesel fuel (and possibly other combustibles like methane). The key is Sonex's elevated compression ratios; dual-fuel burners based on this design would be highly efficient in their spark-ignited, gasoline mode, and would pressurize the fuel enough for autocombustion in the diesel mode.

FUEL INJECTION. Not all interest in lean-burn technology is motivated by European emission standards. In the U.S., Ford Motor (Dearborn, Mich.) recently signed a development agreement with Orbital, the Australian company that has devised a fuel injection system that preconditions gasoline so it is more likely to burn completely. Whereas other systems inject pure fuel into the airstream in the intake manifold, Orbital injects fuel already premixed with air. According to Daniel Hittler, director of fuel injection operations at Orbital's U.S. partner Walbro (Cass City, Mich.), the injected fuel is finely atomized, with each particle surrounded by air molecules that prevent the fuel from coalescing.

Although naturally low in NO_x because of their cool burning characteristics, two-stroke engines present other problems. With both intake and exhaust ports open simultaneously, some unburned gas escapes in the exhaust, resulting in high hydrocarbon and CO emissions and poor fuel economy. Orbital's premixed injection overcomes these tendencies by permitting fuel injection directly into the combustion chambers, timed so that it enters only after the exhaust port is closed. Since the charge is finely atomized and precombined with air, it mixes thoroughly with the fresh air that's already in the combustion chamber, even though compression is well under way. By contrast, conventional fuel injection systems must squirt fuel into the manifold airstream to enable it to mix thoroughly.

While Orbital attempts to market its technology to U.S. and European automakers, the concept is already established in nonautomotive use. Outboard Marine paid Orbital $1 million for its technology, plus a $25 to $60 royalty per engine, and Mercury Marine, Outboard's main competitor, is reportedly negotiating for a license as well.

THE EUROPEAN FRONT. Independent engine design consultant Robert Brooks (Waukegan, Ill.) says that although lean-burn research is being pursued by auto companies around the world, the pace is quickest and most intense in Europe, because of the impending restrictions. Also, since emission standards in Europe will be a little less stringent than in the U.S., auto companies are more hopeful of meeting them without resorting to a three-way converter. The Europeans can be somewhat more open to new approaches, says Pouring of Sonex. For one thing, they don't have an engineering and capital investment in three-way converters already in place, as their U.S. counterparts do, and there is the incentive to avoid having to rely on the USSR or South Africa for the element rhodium, which is needed in three-way converters. Oxidizing converters do not require it.

Thus, independent researchers have a greater chance of commercializing their technologies in Europe. That doesn't mean the prospects for clean-burning engines are hopeless elsewhere. Certainly the Japanese continue to innovate. For example, Mazda Motor in Hiroshima is working on a dual-fuel engine that even eliminates the soot generated when diesel fuel is burned. It uses a ceramic-lined precombustion chamber to start the burning process, elevating temperatures so high that particulates burn off.

Among U.S. automakers, clean-engine development has lower priority, says Brooks, partly because of the entrenchment of three-way converters. However, the Environmental Protection Agency is currently preparing new rules—perhaps requiring automakers to guarantee emission systems for 100,000 miles—that would force Detroit to reexamine its emission technology. Brooks says that such regulations could be passed by year's end.

But observers agree that the first breaks will come in Europe. Says Pouring, "We have to prove ourselves there first." □

Ernest Raia is a former senior editor of HIGH TECHNOLOGY.

For further information see **RESOURCES,** *p. 61.*

COMPUTING WITH NEURAL NETWORKS

Systems that store and retrieve information more like the brain may soon see routine use in pattern recognition and other complex tasks

BY JUNE KINOSHITA AND NICHOLAS G. PALEVSKY

The world's first information revolution occurred not with digital computers and silicon chips, but with neurons, the cells that make up the brain and nervous system of every sentient being. The human brain still reigns as the ultimate computing entity, and even a garden slug performs complex neural computations well beyond the capabilities of supercomputers. Researchers are still a long way from understanding how these natural computers work, but electronic neural models, developed by neurobiologists, physicists, and mathematicians, have shown such promise that they are spawning a whole new computer discipline known variously as neural networking, connectionism, adaptive systems, and neurocomputing.

Most of the seminal work in neural networks has taken place in academic research programs, but the advances achieved have prompted several major high technology companies—including Texas Instruments, AT&T, IBM, Bendix, TRW, BDM, and General Electric—to support in-house neural network projects. At the same time, investment funds are going to a growing number of neural network start-ups, including Nestor (Providence, R.I.), Hecht-Nielsen Neurocomputer (San Diego), Synaptics (San Jose, Cal.), and Neural Tech (Portola Valley, Cal.). At least two of these, Nestor and Hecht-Nielsen, plan to begin shipping products this year.

Neural network products can take several forms. They can be hardware implementations in which the parallel structure of neurons and their interconnections is matched, one for one, with simple processors and communications links; they can be "neurocomputers" that consist of partially parallel hardware and software designed to perform neural network simulations; or they can be total software simulations that run on conventional serial computers.

The types of applications such products might address are varied. But much attention is focused on their reputed ability to handle problems that involve "blurry" and unpredictable data—say, to understand everyday speech or to recognize handwritten letters.

Because such applications cannot be defined by clear-cut rules and data, they are difficult or impossible to tackle with standard digital computing algorithms. It is the prospect of using neural networks as an interface between digital computers and messy, real-world data that has stimulated much of the current activity. "Still, the field is in a very early stage of development, and it will take a significant commercial application to propel it forward," cautions Andrew H. Chapman, a venture capitalist with Eberstadt Fleming (New York).

PROMISING CAPABILITIES. Neural networks are based on theoretical models of how brain cells and their interconnections (synapses) are able to perform exceedingly complex calculations, despite being much slower than electronic switching devices. (Neurons transmit about 1000 pulses per second, while silicon chips can handle a billion or more per second.) Electronically duplicating the full functional range and densely parallel architecture of biological neurons is not yet possible, but simplified models that focus on only the transmission of electrical pulses between neurons have exhibited learning, memory, and other significant capabilities. The faculties of neural networks that are considered especially attractive include:

- Recall of memories even if some individual processors (neurons) fail; this is possible because stored information is distributed among many processors and their interconnections. As a result, performance degrades gradually rather than catastrophically.
- Retrieval of "nearest-neighbor" data if there is no exact match to the requested information. If, for example, a network performing character recognition is confronted with an *A* typed in a different font from the *A* in its memory, it might still correctly identify the new character because it has a high degree of commonality with the stored character.
- Modification of stored information in response to new inputs. Instead of containing hard-and-fast classification rules, a network stores data in a way that expresses the natural rules implicit in the relationships between actual stored items.

MAX AGUILERA HELLWEG

When new data are encountered—such as the different *A* in the example above—these implicit rules adjust to accommodate them.

• "Associative recall"—the ability to retrieve original inputs from a degraded version (a whole picture from a fragment), to link one item with another (a picture of a cat with the response "climb a tree"), or to link an object to a set of categories ("apple" could be associated with categories such as "fruit," "red," and "Isaac Newton").

• Ability to "discover" statistically salient features among the stored data. For example, if a network knows about typical apple varieties and is made to "guess" the color of a new type of apple, it could respond that the probable color is red, but that green and yellow are also possibilities.

• Ability to derive solutions to problems that involve "combinatorial explosion," an exponential blowup in the number of possible answers. This ability, present in certain types of networks, was demonstrated by John Hopfield and David Tank at AT&T for the classic traveling salesman problem (a salesman is given a list of cities, each of which he must visit once and only once, via the shortest total route). Computations performing human-like processes such as speech or object recognition share this combinatorial explosion characteristic, but the Hopfield-Tank method is not yet fast enough for commercial application in this area.

"It took the patience of a Gregor Mendel to do computer simulations of a neural network," says Robert Hecht-Nielsen, whose company is building special-purpose hardware to overcome that problem.

NEURAL NETS AND AI. At first glance, it might seem that neural networks are addressing the same applications as expert systems and other artificial intelligence programs. In fact, although the two fields have competed for research funding (see "A technology with a stormy past," p. 28), they are often more complementary than competitive. Neural networks attempt to mimic biological processes and structures, while AI programs attempt to identify and execute higher-level conceptual processes and relationships that are often based on logic or linguistics. These distinctions have generally caused the developers in each field to focus on tasks that best match their own techniques.

The expert system sector of AI, for example, has begun to achieve commercial success in applications that require the computer to apply a fixed set of logical rules and related facts to a specific problem domain (HIGH TECHNOLOGY, April 1987, p. 16). But the technology has been less successful in applications that require the processing of raw sensory data in a way that is flexible and robust enough to deal with the real, unpredict-

able world. Neural networks, on the other hand, seem to be especially promising for organizing and identifying patterns in just this kind of variable data. As a result, researchers are investigating uses of neural networks that range from image and speech recognition to robotic control.

MIMICKING NEURONS. Neural networks consist of many simple neurons, or processors (real or simulated), that have densely parallel interconnections. The processors communicate across the connections in terms of "activations" and "inhibitions"—signals that excite or inhibit responses by connected processors—rather than with symbols or messages that have higher-level meanings.

A neuron can receive inputs from many other neurons, and if the sum of these inputs exceeds a set threshold value, the neuron will "fire," producing an output signal of a set value. This output is in turn relayed to other neurons. Different neurons can be programmed to have different output values; for example, if neuron A fires, it may output a signal of value 1.0, while neuron B may be programmed to emit an output of 1.25 if its threshold is reached.

In addition, the connection between every pair of neurons is assigned a "weight" or "connection strength" that modifies each output value, determining the actual value of the signal transmitted to attached neurons. In some networks these weights are permanently set, while in others they can fluctuate incrementally according to the network's activity. In a software simulation of a neural network, each synapse's weight is indicated by a numeric value, and the magnitude of the transmitted signal is a neuron's output multiplied by this weight. Thus, if neuron A outputs a signal with a magnitude of 1.0 and its connection to neuron B has a weight of 0.25, neuron B will receive a signal with an amplitude of 0.25 (1.0 times 0.25). If, on the other hand, the weight were −0.25, neuron B would receive a signal of −0.25, one that would have an inhibiting, rather than activating, effect. In an actual hardware implementation of a neural network, the weight of the synapses can be achieved electronically through the use of variable resistors that control the amount of current transmitted along each connecting wire.

Some early researchers in neural networks hoped to create intelligence from randomly wired devices, but it is now recognized that neural networks require painstakingly designed architectures. There are now about a dozen basic network models, differing from one another in the way the nodes are interconnected and in the rules they use to produce a given output signal for different sets of input signals. Some networks are fully interconnected grids, with each processor directly connected to every other processor, while others embody treelike or layered architectures.

DATA REPRESENTATION. A key feature of neural networks is that information is represented in a distributed way—in the weighted connections—rather than in a discrete string of code stored in a single processor's memory. As a simple example, suppose that the letter *A* is represented by a 10-bit binary code of *1*s and *0*s. In a network, 10 input neurons might receive this data (one neuron per bit) and relay it over weighted connections to neurons in the next layer. Each neuron in this layer might be connected to four input neurons and be designed to fire a pulse if the sum of the signals it receives is 1 or more. Here the synaptic weights come into play. If all the weights between the input and second layer of neurons were 1, for example, a second-layer neuron would need only one of its four input neurons to have a bit with the value of 1. On the other hand, if the weights were all 0.5, then the second-layer input would not fire unless at least two of its input neurons were *1*s.

Output signals from the second layer are passed over weighted synapses to a third layer, where the process of neuron activation and inhibition occurs yet again. This sequence can be repeated through a number of layers until the signals reach an output layer. The pattern of active and inactive neurons in this last layer is equated to the response: "This is the letter *A*." A different string of 10 input bits would propagate through the network across a different pattern of connections, and would result in its own characteristic output pattern.

The creation of such signal propagation patterns to represent different types of data is useful because it ensures that the network's performance is not totally dependent on any individual neurons. For example, if one of the input neurons failed, or the input pattern itself were incomplete, the pattern generated by the remaining neurons may still be complete enough to achieve the correct output. For a similar reason, a network will come up with its "best match" for inputs that it has not been set up to recognize, because it would respond the same way to an unknown pattern as it would to the known pattern that most closely resembled it.

SETTING SYNAPTIC WEIGHTS. The weights of the synapses, clearly critical in determining the pattern of signal propagation, can be set in either of two ways. The synapses can be fixed permanently in advance to give the network the properties it needs to compute a certain category of problems. Alternatively, the network can be "self-organizing," containing rules for learning that cause the synapses to adjust themselves during "training sessions" or in response to new inputs. Self-organizing networks can improve their performance and organize data in ways that do not exist in the system *a priori*.

Probably the best-known type of preconfigured network is the Hopfield net, named for John Hopfield, a biophysicist and chemist with joint appointments at Caltech and AT&T Bell Laboratories. Hopfield's mathematical analysis of the computational properties of a neural network, described in a 1982 National Academy of Sciences paper, is given much of the credit for the current interest in the field. Exploiting an analogy to energy states in physics, Hopfield demonstrated a "computational energy" function, likened to a terrain of rolling hills and valleys, in which the solutions can be made to lie in the valleys by adjusting the synaptic weights. Just like a physical system, the network seeks its "lowest-energy" state, and can thus match new input patterns to those already embedded in the network through the proper setting of the connection strengths.

A Hopfield network can function as a "content-addressable" memory—one that can be reconstructed from partial or inaccurate cues. A 10-bit input string, for example, is stored in a network configured as a 10-by-10 matrix in which the bit string runs both vertically and horizontally. The Hopfield algorithm determines the value of each element in the matrix according to the relationship between the values of bits in the input string. In a simplified version, if the third and fourth bits are both 0, then the element occupying the third row/fourth column would be −1; if they are both 1, it would be +1; and

By performing mathematical analyses of how neurons could act collectively to process and store information, Caltech's John Hopfield reinvigorated the flagging neural network field.

if one is 0 and the other is 1, it would remain at 0. Then, if the system is cued on an incomplete input in which the fourth bit is missing, it can reconstruct the fourth bit from the values stored in the matrix elements.

This kind of network can store several overlapping strings of data and still be able to retrieve each one. Beyond a certain point, however—typically when the number of strings stored reaches about 10 to 15% of the number of matrix elements, or neurons—the system's performance starts to erode because the same connections are shared too many times among different strings of data.

SELF-TEACHING SYSTEMS. Other types of networks are not preconfigured in this way. Instead, they contain learning rules that lead to appropriate responses while discouraging inappropriate ones. Most learning algorithms are based on a rule proposed in 1949 by neurophysiologist Donald Hebb, in which simultaneous activity in two neurons causes the connecting synapse to become "stronger," while inactivity causes a synapse to atrophy. This rule permits the network to reinforce response patterns that occur often, as though it were learning from experience.

One self-organizing program, NETtalk, has demonstrated an ability to learn to read English text out loud, achieving a 95% performance level on each letter without the benefit of any preprogrammed linguistic rules. The brainchild of Johns Hopkins biophysicist Terrence Sejnowski and Princeton graduate student Charles Rosenberg, NETtalk simulates only 231 neurons (and 10,346 connections) arranged in three layers.

NETtalk's input layer has five neural groups, each with 29 neurons for transforming the 26 letters in the alphabet plus spaces, commas, and periods into 29-bit patterns. The output layer, consisting of 26 units that encode phonemes and stresses, drives a sound synthesizer. The middle layer has 60 "hidden units" designed to improve the network's ability to associate an input with the correct output. Each unit in the input layer is connected to every unit in the middle layer, and all of these in turn are connected to every output unit.

The input layer examines a parade of text five characters at a time. The network associates the middle character of each group with an output pattern. The two characters on either side of the middle character place constraints on the output, because pronunciation depends to a great extent on a character's context in a word. Like a child, the network starts out untrained, and produces a stream of mean-

A TECHNOLOGY WITH A STORMY PAST

Neural networks first burst on the scene some 30 years ago, propelled in large part by the work of Cornell University's Frank Rosenblatt on simple pattern-learning networks called perceptrons. One of these consisted of a 400-photoreceptor array and was trained to learn simple images, such as letters of the alphabet. The perceptron was able to group similar objects into categories on its own, and although it had many shortcomings—for example, it would become confused when confronted with a pattern against an unfamiliar background—it created a sensation. Some of its more extreme exponents believed that they were on the brink of building a brain; one had only to wire enough perceptrons together. Rosenblatt proclaimed that the future lay with perceptron-like devices, rather than with artificial intelligence programs that simulate the brain's activity by symbolically representing ideas.

Within a few years, there were perhaps 1000 people in the world doing perceptron research. This deeply troubled such scientists as Marvin Minsky and Seymour Papert—renowned for their AI research at MIT—who suspected there were serious flaws to the whole approach. "We were faced with a shortage of researchers in AI, and were watching people throwing away their lives on perceptrons," recalls Minsky. In 1969, five years after they began work on it, Minsky and Papert published *Perceptrons*, a mathematical dissection of a pared-down perceptron, in which they proved that the concept suffered from serious limitations. For one thing, they wrote, it was impossible to determine which connections were responsible for producing a given output. For another, the perceptron could not distinguish binary inputs with an odd number of *1*s from those with an even number of *1*s—which meant that it could not tell apart inputs that differed by only one bit. They conjectured that such limitations would prove true for more complicated neural networks.

Although this conjecture later proved only partly true, *Perceptrons* dealt a devastating blow to neural networks. Funding ground to a halt, and young scientists shunned the topic, turning instead to AI research. Bernard Widrow, a Stanford professor and neural network pioneer, recalls: "My impression was that Minsky and Papert defined the perceptron narrowly enough that it couldn't do anything interesting. You can easily design something to overcome many of the things that they 'proved' couldn't be done. It looked like an attempt to show that the perceptron was no good. It wasn't fair."

Counters Minsky: "That's like saying that you shouldn't bother with linear differential equations because the real world is nonlinear. All of our theorems are correct, and nobody has proved that the current machines can deal with problems we discussed," such as separating relevant patterns from irrelevant background. Minsky and Papert plan to publish a new edition of the book this autumn, with an additional chapter discussing the main problems of the current network models.

But if there were so many problems with perceptrons and neural network models, why the reawakening of interest? Minsky concedes that his own past criticisms were perhaps "overkill," and that "the perceptron was a new type of basic learning machine—it was a great event." He believes that the very simplicity of such structures argues for their existence somewhere in nature. The reason neural models were so long eclipsed by AI, he thinks, is that at the time, AI itself was a young field that offered more promise for delivering exciting and powerful results—results that have since become commercial realities in the form of expert systems and natural-language programs. "You would have been crazy to be doing perceptrons when you could get so much more dramatic results with AI," says Minsky.

Now, however, the problems AI has not successfully solved are becoming more apparent and are offering fresh opportunities for research, while AI itself has become crowded and fiercely competitive. (In 1970, 200 people attended the American Association of Artificial Intelligence's annual meeting; last year's meeting attracted nearly 10,000.) In addition, today's hardware for supporting neural networks is 1000 times more powerful than what was available back then, and there have been impressive theoretical advances such as the Hopfield network.

Still, Minsky argues that neural networks can so far do nothing that can't be done by other means. "When they do something that can't be done any other way, *that* will be revolutionary."

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ingless babble. Each attempt is compared with a desired output (a phonetic transcription of a person reading the text), and the system measures the "error distance" between its output and the model. It then adjusts the synaptic weights so that the error becomes smaller. The performance improves markedly with further training. The continuous stream of babble first gives way to bursts of sound, as the network "discovers" the spaces between words. It then begins to catch on to the difference between vowels and consonants. After being left to run overnight (in a highly inefficient serial simulation on a VAX), NETtalk is talking sense.

PATTERN MATCHING. Proponents of neural networks point to these abilities to automatically organize stored information and handle unfamiliar and contradictory data as evidence that the systems can perform applications such as pattern recognition, robotics and control, and knowledge processing with greater speed and flexibility and at lower cost than traditional computers. NETtalk, for example, took one summer to develop and in 10 hours trained itself to the performance level of DECtalk, a text-to-speech program that took several years to build and that reflects decades of accumulated linguistic expertise.

Nevertheless, while DECtalk is an actual product, NETtalk is still a research project. What's more, it may be some time before commercial neural networks actually surpass the capabilities of existing computer products. For example, Nestor's first product, NestorWriter—which runs on an IBM PC/AT and is partially based on a neural network pattern recognizer—will read handwritten text that is entered on a digitizing pad, something Pencept's Penpad can do already. However, unlike the NestorWriter (now in the prototype stage), Pencept's product cannot teach itself entirely new symbols on the spot.

Instead of programming a complete set of rules for recognizing characters, Nestor's founders, Leon Cooper and Charles Elbaum, physics professors at Brown University (Cooper won a Nobel prize in 1972), designed a system that would figure out some of the rules for itself. To perform a pattern recognition task such as identifying characters, says Cooper, "you have to define very complex boundaries between classes of objects, such as letters." In addition, he notes, the system "has to decide which features should be looked at in defining the classes." When NestorWriter tries to distinguish between a *C* and an *O*, for example, it must determine whether the curve of the letter is open or closed. But if it is trying to tell

C from *U*, it has to consider the letter's orientation. The great variation in handwriting—for example, some *O*s aren't quite closed loops—makes it very difficult to define the boundaries between classes.

NestorWriter is trained on typical handwriting samples, but can be trained further on a particular user's style, typically in one or two tries. It was able to learn even truly idiosyncratic scrawls after half a dozen repetitions. To get up to commercially acceptable speed, NestorWriter uses a proprietary combination of neural networking and other techniques. "You tell it every rule you can easily write, and have it learn those that can't be easily written," explains Cooper. An easy rule might be a list of letters that can be written in one stroke (*C, O, V, Z*, and so on). "Difficult rules," he says, "are things like when does a *2* become a *3*, or when is the squiggle up there important and when isn't it?"

In a dramatic demonstration of neural networks' ability to accumulate new knowledge, Terrence Sejnowski at Johns Hopkins created a system that taught itself to read English text out loud.

The company's most significant achievement so far may be its system that recognizes handwritten kanji (Japanese characters). Nestor claims that it can read 2500 commonly used kanji with about 90% accuracy and can recognize them as fast as they are written, making it practical for use as a Japanese word processor. In fact, Nestor had struck a licensing deal with Digital Equipment to develop such a word processor, but the deal fell through last September. Soon after, a Japanese brokerage firm, Nikko Securities, stepped in with an arrangement that Nestor hopes will lead to licensing agreements with a Japanese firm.

One Japanese company, Asahi Chemical, is going to market a speech recognition network invented by Teuvo Kohonen, of the Helsinki University of Technology, one of the world's most prolific and influential neural network theorists. According to *Intelligence*, a newsletter that reports on current developments in neural networks, a prototype of Kohonen's speech recognizer has been built on a circuit board. It reportedly consists of a self-organizing neural network that can extract and store features of spoken words, combined with a non-neural-network component that performs higher-level analyses of vocabulary, grammar, and semantics. The prototype, which is trained in the grammatically similar Finnish and Japanese, recognized the speech samples used for training with 98% accuracy, and achieved 93–94% accuracy when confronted with new samples. Kohonen says the system can be trained in other languages without great difficulty.

The patterns identified by neural networks are not limited to writing or speech. TRW, Bendix Aerospace, and the University of Pennsylvania are testing neural networks that can be trained to identify target vehicles by their radar or sonar patterns. TRW has developed an experimental system that learns to recognize vehicles by doppler-shifted radar traces. Nabil Farhat of the University of Pennsylvania, meanwhile, has built a 32-by-32-neuron optoelectronic network that stores complete radar images of three or four vehicles and can identify target vehicles from only 10 to 20% of the total pattern.

R. Paul Gorman of Bendix Aerospace has used Sejnowski's NETtalk algorithm to build a neural network that can recognize underwater targets by sonar. To assess the network's performance, he observed the types of cues that human experts considered when trying to identify sonar targets, and then used these rules to construct a classifier program (a conventional, non-network type of pattern recognizer). In experiments, the network outperformed the classifier pro-

gram, getting 100% versus 94% on the training set of data, and 88% versus 84% on a new test set. Moreover, once the two systems had been set up, the classifier approach required 10 months of experiments to extract the rules from human experts, while the network completed the analogous task in about three hours.

ROBOTICS AND CONTROL. Another important area of use for neural networks is control applications. In fact, their role in such applications has a relatively long history. In 1959, Bernard Widrow, a Stanford professor and one of the earliest pioneers in the practical application of neural network theories, invented a device called Adaline (short for "adaptive linear element"), which was based on simple neuronlike elements. Widrow was able to employ Adaline's algorithm to develop the adaptive filters used to clean up echoes on telephone lines. The same technology is applied in adaptive equalizers, which are used in high-speed telephone modems to reduce data transmission errors and in adaptive antennas that can cancel jamming signals.

The reason echo cancellation lends itself to a neuronlike approach is that telephone lines are electronically chaotic; voltage and impedance fluctuate continually, depending on routings and activity along the line. If the echo problem were tackled with mathematical equations that described this system, the huge number of possible voltages would make the process prohibitively slow. The adaptive filter, like other systems based on neural networks, can accept a real-world analog input, compare it with a stored pattern that represents the desired input level, and modify it as necessary; the filter's error-correcting feedback signal automatically controls the input voltages so that they produce an echo-free signal.

Other neural networks may one day be used to handle even more difficult problems in the control of robotics and industrial processes. Certain industrial machines, for example, require complex start-up procedures that cannot easily be described mathematically. Robert Hecht-Nielsen, founder of Hecht-Nielsen Neurocomputer, proposes that a neural network could learn patterns in this complicated start-up behavior and then aid the engineers by offering advice on setting the control parameters.

Meanwhile, neural network models of the cerebellum, the brain region that coordinates physical motion, could lead to improvements in robot control. The cerebellum occupies a considerable part of the brain, and its microorganization is well understood, thanks to its simplicity (it consists of only five types of cells) and regularity. According to a hypothesis called the Tensor Network Theory, the cerebellum transforms one set of physical coordinates, such as the location of an object as determined by the position of eye and neck muscles, into another completely different set of coordinates, such as the angular positions that the arm muscles must assume in order for the hand to touch the object.

This process can be described mathematically by a function written in matrix form that transforms a vector in one coordinate system into a vector in another. This can be achieved by a gridlike neural network, as has been shown by Andras Pellionisz, a professor of biophysics at New York University Medical Center and one of the originators of the theory. On both a VAX and a Macintosh Plus he has simulated robot arms and cat limbs that move with remarkably natural grace. Pellionisz owns a patent based on this work and is forming a company, International Neurobotics, to commercialize it.

Although some believe neural networks will benefit from optical processing methods, AT&T's Hans Peter Graf says the required lenses and lasers are too bulky for use in networks where hundreds of them might be required.

HARDWARE SUPPORT. One barrier to the growth of neural networks—a lack of suitable computers—is just beginning to crumble. Traditional serial machines are simply not very efficient at running simulations of highly parallel neural structures. Hecht-Nielsen discovered this in 1968 when he became interested in the neural network research being done by Stephen Grossberg, now director of the Center for Adaptive Systems at Boston University. When Hecht-Nielsen wrote his own neural network program, he found it "would take forever to run. It took the patience of a Gregor Mendel to do computer simulations of neural networks."

As a first step in overcoming this problem, Hecht-Nielsen, Michael Myers, and their colleagues at TRW's Rancho Carmel AI Center built two "neurocomputers"—the 65,000-neuron MARK III-1, which sells for $60,000, and the 250,000-neuron MARK IV, which is used exclusively by the Defense Advanced Research Projects Agency for top-secret tests in "real-world environments." These machines are designed to implement neural networks efficiently, using partially parallel hardware to do network simulations. The MARK III-1, for example, contains eight physical processors, each emulating roughly 8000 neurons. In tests of an earlier version, it ran 21 times as fast as a simulation on a VAX superminicomputer.

Hecht-Nielsen left TRW last fall to start the company that now bears his name. Grossberg and a BU colleague, Gail Carpenter, have signed on as scientific advisers. The company plans to market a complete line of neurocomputers designed to function as peripheral processors attached to conventional computers. At the beginning of this year, the firm announced its first product (due to ship later this year), ANZA, a $15,000 coprocessor board designed to be integrated into an IBM PC/AT. ANZA will emulate a network of 30,000 neurons with 300,000 interconnections and will be able to establish 25,000 connections per second, according to the vendor. Working with such products, says Hecht-Nielsen, "some of our OEM clients will develop applications that are going to show up on the consumer market within the next three years."

Still, even neurocomputers like Hecht-Nielsen's, which simulate large numbers of processors, may be far too slow for many real-time applications. Thus researchers at AT&T, MIT, and Caltech are investigating ways to build neural networks directly in integrated circuits, with a physical component for each neuron, and connection wires with devices such as resistors to provide synaptic weights. AT&T's Electronic Neural Network (ENN) chip, for example, has etched onto it 256 neurons—built from transistors—and more than 100,000 resistors, which provide the synapses. The processing task that the chip will perform must be carefully analyzed beforehand because the resistance of each connection is permanently "burned in" at the time of fabrication. In the future this type of chip could be made as dense as half a billion synapses per square centimeter, because the resistors are tiny and the circuits require fewer layers of lithography than conventional memory chips.

The ENN chip is being tested (in computer simulation) as a way to compress the bandwidth of video images so they can be carried over telephone lines in real time. Instead of transmitting all the color

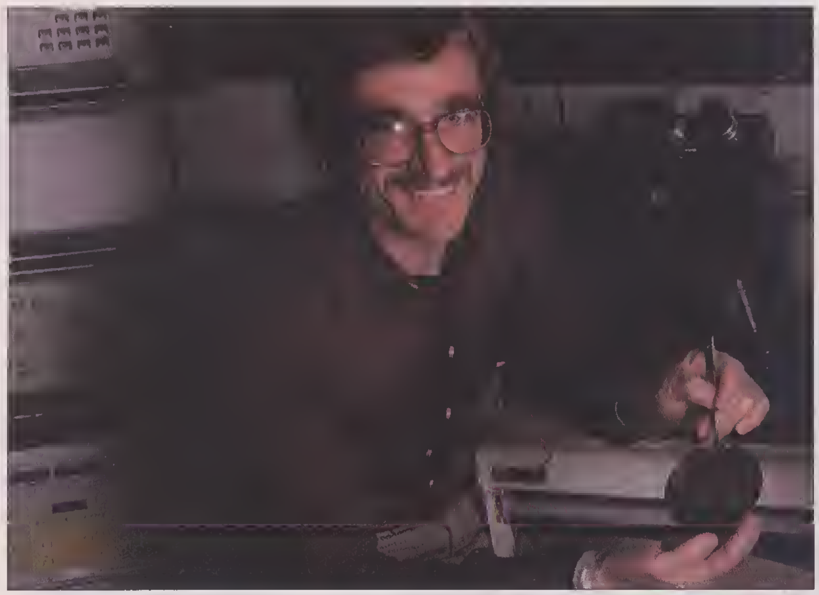
and gray levels pixel by pixel, it divides up the picture into small frames, and for each frame finds a simpler pattern that closely matches it, so that the system doesn't have to transmit as much data. AT&T is also testing a 54-neuron programmable chip whose synaptic strengths can be changed by an external program, enabling the chip to be used as a programmable associative memory.

Other prototype neural network chips have been developed by Caltech's Carver Mead, a pioneer in very-large-scale integration design. Mead has also built a "silicon retina" chip that uses a mixture of analog and digital components to pick up and process sensory inputs. The chip outperforms all other vision systems in the detection of motion, according to Michelle Mahowald, a graduate student working with Mead. The retina chip "is not a digital abstraction of what a neuron does," she says. "The chip uses the physics of the components themselves to do the computations." For example, capacitors on the chip yield a measure of the change in light intensity, enabling it to detect motion continuously. In contrast, a vision system based on a TV camera gets snapshot-like frames at fixed intervals and then has to compare them pixel by pixel to detect motion.

Mead recently joined Synaptics, a neural network company founded in January 1986 whose staff includes neurobiologist Gary Lynch of the University of California at Irvine, and Federico Faggin, founder of Zilog. "Our starting point is real biology," says president and CEO Lauren Yazolino, adding that Mead's silicon retina "works marvelously well because it's really built the way the retina is." The company will design neural network chips and is considering a number of possibilities for its first product, including voice recognition, sonar image recognition, and gas chromatography. Synaptics hopes to become a general neural technology company, not just a maker of a few types of neural network devices: "We want to be the Genentech of neural networks," says Yazolino.

Researchers in optical information processing are also intrigued by neural networks. Because synapses vastly outnumber neurons, light beams—which can cross one another without signal interference and can be made infinitely dense—may offer an ideal way to form these connections. To totally interconnect a thousand neurons would require a million wires on a chip, but in an optical neurocomputer each neuron could simply emit light that would be picked up by the other neurons. In the first such devices, neurons will probably consist of light-emitting diodes that direct their light onto an optical mask to permit different synaptic weights. Prototypes have been built by Farhat at the University of Pennsylvania, by Demetri Psaltis of Caltech, and by Ravindra Athale of BDM (McLean, Va.).

"With optics, it's relatively simple to make neural networks," says Farhat, "and there's a tremendous amount of advanced optical technology that can be used." Hecht-Nielsen predicts that optical neurocomputers will be on the market within 10 years. It is in such computers, he believes—not in serial von Neumann machines—that all the work in optics will finally pay off. However, Hans Peter Graf, a member of AT&T's ENN chip project, says, "we looked into optical methods but decided the VLSI approach is more promising," because lenses and lasers make optical systems too bulky for broad applications.



START-UP COMPANIES

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(619) 546–8877
Founder: Robert Hecht-Nielson

Nestor
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Providence, RI 02906
(401) 331–9640
Founders: Leon Cooper & Charles Elbaum

Neural Tech
177 Goya Dr.
Portola Valley, CA 94025
(415) 854–8389
Founder: John Voevodsky

Synaptics
2860 Zanker Rd., Suite 105
San Jose, CA 95134
(408) 434–0110
Founder: Gary Lynch

WILL THEY SUCCEED? Although a wide range of development projects are under way, neural networks have yet to prove themselves in the market, and some observers remain skeptical of the capabilities attributed to them. "There is a whole lot of hype and nonsense in the field, which takes away from the scientific credibility of the people who have been doing legitimate work," claims Danny Hillis, founding scientist at Thinking Machines (Cambridge, Mass.). "There *has* been important scientific progress, but some people are grossly overportraying what the machines can do." (Hillis stresses that his firm's massively parallel Connection Machine should not be confused with "connectionist" neural network products.)

On the other hand, Stanford's Widrow says, "I believe all the hype." Nevertheless, he counsels caution in expecting too much too soon from neural networks. "What worries me is that many people don't realize how hard the problems are. Even if something works beautifully in the laboratory, it still takes 10 years to get it out in the marketplace." □

June Kinoshita and Nicholas G. Palevsky are freelance writers specializing in high technology and East Asian affairs. Research assistance for this article was provided by Annette Kondo.

For further information see **RESOURCES**, *p. 61.*

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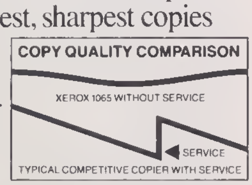

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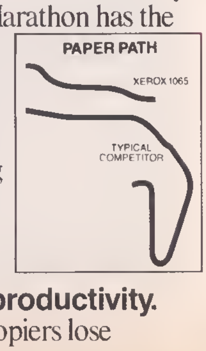

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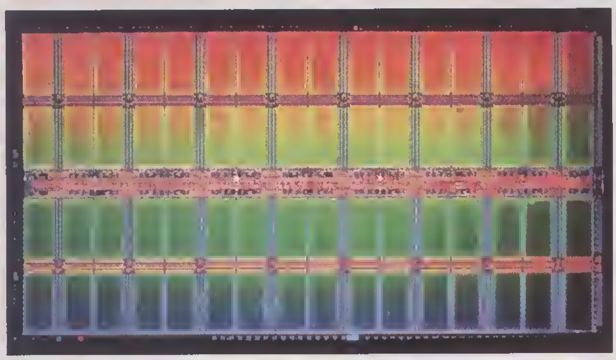


As Japan takes the lead in basic chips, American firms look to R&D collaboration and increased federal funding

BY JEFFREY BAIRSTOW

For most of the past three decades, California's Silicon Valley symbolized the vitality of American high technology. Innovative semiconductor companies—the source of the region's name—devised complex and powerful chips that in turn stimulated a wide range of electronics and computer businesses. But today, Silicon Valley and other electronics-manufacturing areas across the U.S. are in a slump, having lost market share—and sometimes entire markets—to the more efficient Japanese semiconductor makers and to manufacturers in the cheap-labor environments of Korea, Taiwan, and Singapore. This slump is not seen as some short-term phenomenon. "The U.S. semiconductor industry is at a crucial turning point," concluded a recent assessment by the CIA for the Pentagon's Defense Science Board. "It fundamentally cannot compete in its current form."

Although the U.S. still leads the world in the design of complex microprocessor chips and application-specific integrated circuits (ASICs), the major semiconductor companies are falling behind, largely because the Japanese are better at making high-volume commodity ICs such as memories. An analysis by the investment banking firm of Hambrecht & Quist (San Francisco) suggests that Japanese firms' yields—the proportion of usable chips from a silicon wafer—are three times those of their American counterparts, owing to their heavy investments in automated semiconductor-manufacturing equipment, meticulous maintenance pro-

Above: National Semiconductor's Charles Sporck, prime mover of the Sematech industry consortium. Opposite: The 4-megabit chip—IBM can produce it, but so far the U.S. merchant semiconductor makers cannot.

cedures, and extremely rigorous quality control. By paying more attention to manufacturing processes, the Japanese now lead the world in making high-volume chips.

A recent Defense Science Board (DSB) report on future sources of chips for the military singled out seven areas in semiconductor manufacturing in which the U.S. led only 10 years ago but has now fallen behind: processing knowledge and skills, fabrication and testing equipment, particulate control (important for cleanrooms), automation, device packaging, materials and supplies, and information management (see "The military's task force on chips," p. 38). The report also pointed out that the fragmented and highly competitive nature of the U.S. semiconductor-equipment industry forces each company to be highly protective of its capabilities; there is little or no sharing of technology. And many of these companies, unlike their Japanese competitors, have only a shallow commitment to long-range goals.

If the DSB assessment is correct, and many industry observers and more than a few industry executives believe that it is, the U.S. semiconductor industry is in danger of continuing its decline. Such prospects have far-reaching commercial and military implications. "For the first time, the U.S. would no longer dominate the critical technologies needed for military power and industrial development," says Charles Ferguson, a postdoctoral fellow at MIT's Center for Technology, Policy and Industrial Development. Many industry observers argue that if U.S. makers of computers and telecommunications equipment—the products that typically require the most sophisticated semiconductors—become dependent on overseas suppliers (especially the Japanese), they will be at a competitive disadvantage. As the Japanese become technology leaders, they will grow much more reluctant to sell advanced chips to the U.S.; at the very least, Japanese firms will get them first.

Meanwhile, the Pentagon is becoming increasingly worried about dependence on overseas chip suppliers for chips for military equipment vital to national defense. In a conflict, or in politically sensitive situations, supplies could be cut off. James J. Egan, an official with Aerospace

Corp., points out that close to 100 of the unique semiconductors used in America's military space program are supplied by foreign manufacturers because there are no U.S. suppliers. And many military electronics experts believe that the U.S. is already falling behind in R&D on gallium arsenide devices, which are expected to underlie the next generation of high-speed semiconductors for computers, satellites, and weapons systems.

In any case, MIT's Ferguson claims that the "merchant" semiconductor companies—those whose main business is making standard chips such as random-access memories in huge volume and selling them on the open market—are on their way out. They will be replaced, he says, by vertically integrated companies such as Fujitsu in Japan and IBM in the U.S., which make their own commodity chips and incorporate them into their own electronic equipment. Few U.S. semiconductor makers have the extensive financial resources to survive against the Japanese conglomerates. "In 10 years only two of the top 10 semiconductor makers will be American—IBM and Texas Instruments," says Richard Skinner, president of the consulting firm Integrated Circuit Engineering (Scottsdale, Ariz.). "Six will be Japanese, one Korean, and one West German."

The rapidly rising yen has tempted a few Japanese companies to consider buying some of the faltering U.S. semiconductor makers. Recently, in a move that sent shock waves through Silicon Valley, Fujitsu offered to buy an 80% share of veteran IC maker Fairchild Semiconductor from its French parent, Schlumberger. This purchase would have allowed Fujitsu both to establish itself in the U.S. marketplace and to acquire advanced semiconductor technology such as Fairchild's 32-bit microprocessors. However, after the Defense Department, the CIA, and the Commerce Department asked the White House to block the deal—primarily on the grounds of national security (Fairchild is a major supplier of critical military chips)—Schlumberger decided not to go ahead with the sale. Industry observers believe that the government's success in halting this deal will discourage Japanese companies from attempting other, similar purchases.

Some observers nevertheless see a bleak future. For example, Clyde Prestowitz, former adviser on Japanese trade to Commerce Secretary Malcolm Baldrige, claims that "by the early 1990s, the Japanese will dominate every segment of the market—with the possible exception of a few custom chips." But others expect to see the U.S. semiconductor industry cultivate some important niches. "We continue to lead the Japanese in complex, higher-value ICs such as microprocessors, digital signal processors, and ASICs," says Hutcheson. The implication is that the U.S. may be better off leaving the lower-priced, higher-volume commodity IC business to the Japanese and Koreans while concentrating on innovative devices with lower volumes but higher profit margins. "The industry will continue to seek out markets with rapid growth and high profitability," claims Andrew Kessler, an analyst with PaineWebber (New York). "Our climate continues to be innovative, and we have the engineering talent to stay ahead of the rest of the world."

Kessler believes that companies with a significant investment in microprocessors and a substantial customer base—notably Intel, which makes the microprocessor chips for IBM Personal Computers, and Motorola, with its series of chips for Apple computers and the major workstation vendors—are likely to prosper. In addition, he says, the innovative nature of U.S. business is likely to continue encouraging new start-up companies that will seek out niche markets. For example, several smaller companies, such as VLSI Technology, LSI Logic, and Sierra Semiconductor, have been very successful in ASICs, which require sophisticated design services and close customer contact but do not require the huge investment in manufacturing facilities needed to make merchant memory chips.

In large dynamic random-access memories (DRAMs), where Japanese companies now have more than 90% of the world market, the U.S. merchant semiconductor makers have practically thrown in the towel—despite a recent trade agreement designed to achieve the opposite effect. Because memory prices dipped so low, American semiconductor manufacturers accused the Japanese of overseas dumping—selling chips in the export market below their manufacturing costs—and appealed to the government for trade protection. After extensive investigation by the Commerce Department, a trade pact was concluded with the Japanese, requiring them to sell in the U.S. at prices to be determined by Commerce from Japanese-supplied data.

Unfortunately, the trade pact had the initial effect of raising memory prices dramatically in the U.S., to the horror of many computer and electronics firms, which threatened to move their manufacturing overseas. In recent months, however, U.S. memory prices have begun to come down again to almost pre-pact levels as Commerce adjusts the market prices to reflect more recent Japanese manufacturing data. In its net effect, the trade pact appears to have been a financial windfall for Japanese chip makers, which have been happy to accept more money for their chips in the United States. For the U.S. chip makers, the trade pact appears to have been a dismal failure: memory prices have not stayed high enough to encourage them to reenter DRAM manufacturing.

Nevertheless, one major U.S. semiconductor manufacturer—IBM—continues to make its own memory chips. IBM manufactures 1-megabit DRAMs, the current state of the art, for use exclusively in its own computers. IBM is also actively developing 4-megabit DRAMs—the next generation of semiconductor memories, expected to become widely available in 1988. Such a huge, integrated company can afford the massive investment required for developing new technologies and installing new production processes; it may even be tempted to sell chips on the open market, just as its counterparts in Japan do already. (Digital Equipment Corp. manufactures its own complex ICs, notably for the MicroVax II minicomputer, but not commodity chips. DEC is said to be interested in selling some of its microprocessor output).

The U.S. is superior in the design of complex ICs, but the gap is closing fast. Technology leadership may soon be established abroad.
—DSB task force report

The reason for the great concern over memory chip making is that memories have traditionally been the driving force in pushing forward semiconductor design and manufacturing technology. The highly regular design of memories allows their cells to be shrunk much more easily than random logic to pack more circuitry on a chip. Thus, memory chips are usually the first to be made with a new, smaller feature size, and production problems for denser chips are most often solved with the initial production of new memory designs.

BENNO FRIEDMAN

PaineWebber's Andrew Kessler: "Companies with a significant investment in microprocessors and a substantial customer base are likely to prosper."

At the beginning of this decade, the 16-kilobit DRAM was in volume production, replaced only three years later by the 64k DRAM and currently by the 256k DRAM. As memory sizes increase, the level of integration on a chip rises and production becomes correspondingly more demanding. For example, a 1-megabit DRAM has more than a million transistors on a piece of silicon about a quarter of an inch square. The separation between devices on the chip is about 1 micron, close to the limits of current manufacturing technology. By the time 16M DRAMs are manufactured—a few years from now—that separation will have to be 0.5 micron or less, which is probably beyond the limits of conventional optical lithography and may require newer and more expensive techniques such as x-ray or deep-ultraviolet lithography. Few companies can afford to develop such complex equipment.

In memory chips, a new generation of devices—in which the number of bits is quadrupled—appears roughly every three years. Currently, the 256k DRAM is approaching peak production, and the next generation, the 1M DRAM, is starting to go into production. Meanwhile, 4M DRAMs are in the active development stage and will probably be manufactured in 1988, as the 1M DRAM approaches peak production. Consequently, it is too late for U.S. merchant manufacturers to enter the 1M DRAM market, and they may already have missed the boat in the development of a competitive 4M DRAM. The costs of developing memories and the production processes required for their manufacture are increasing rapidly. Many observers therefore feel that, given the overall weakness of the industry today, the investment required for the 16M DRAM would be beyond any one U.S. semiconductor maker.

As a result, the Semiconductor Industry Association (SIA) in Cupertino, Cal., has adopted a proposal by Charles Sporck, president of National Semiconductor (San Jose), that U.S. merchant semiconductor makers form a consortium to develop manufacturing techniques for DRAMs. The plan, known as Sematech (semiconductor manufacturing technology), calls for substantial funding from semiconductor companies and the Depart-

RICHARD HOWARD

MIT's Charles Ferguson: "The merchant semiconductor companies will soon be replaced by the vertically integrated companies such as Fujitsu in Japan and IBM in the U.S."

THE MILITARY'S TASK FORCE ON CHIPS

The Pentagon, concerned about the slump in America's chip industry, organized an investigative body in December 1985 called the Defense Science Board Task Force on Semiconductors. Its purpose: to assess the U.S. military's possible dependency on foreign sources for semiconductor devices. Chaired by Norman R. Augustine, president of Martin Marietta and a former undersecretary of the Army (see list below), the task force presented its report to Secretary of Defense Caspar Weinberger in February.

PRINCIPAL FINDINGS

• A significant fraction of the chips used in the latest defense systems are either made or packaged overseas. If steps are not taken immediately to assure availability from domestic sources, the U.S. could become dependent on foreign chips in wartime, or be forced to rely on technologically inferior alternatives. A production base is needed to avoid this dependency.

• DRAMs are a driving force in semiconductor manufacturing technology. Because they are the most demanding chips to manufacture competitively, and their development paces progress in other semiconductor technology, the loss of DRAM production to Japanese and other overseas suppliers will damage the U.S. semiconductor industry. It will also hurt chip-manufacturing equipment makers and material suppliers, which will not have a viable domestic market. And it may cause industries that use memory chips extensively, particularly computers and telecommunications, to move offshore.

• The U.S. is superior in the design of complex integrated circuits and in the production of low-volume application-specific ICs, but the gap is closing fast. Technology leadership may soon be established abroad.

• Although the U.S. captive semiconductor makers (firms that embed their semiconductor production in their own end products) have substantial technological and production resources, they are not significant suppliers of semiconductors to the Defense Department, since they do not sell semiconductor devices on the open market. Thus the Pentagon cannot depend on the captive makers for military semiconductors. Furthermore, the captive makers are dependent on a viable U.S. semiconductor materials and manufacturing industry base and could themselves be hurt if overseas equipment suppliers took the lead in production technology.

RECOMMENDATIONS

• Establish a Semiconductor Manufacturing Technology Institute to advance the technology base for efficient, high-yield manufacture of advanced semiconductors, with a particular focus on the 64-megabit DRAM. The institute—a consortium of semiconductor industry manufacturers—would develop, demonstrate, and produce selected devices for DOD needs and transfer its advanced production technology to member companies. Initial capitalization of $250 million would be provided by the members, and additional support would come from the Pentagon ($200 million per year for five years). The speedy formation of the institute is the task force's most crucial recommendation. "If we spend a year talking about this and not getting under way," says Augustine, "we'll approach the point where we may not have a recoverable situation."

• Establish Centers of Excellence for semiconductor science and engineering at eight universities. These centers would develop new approaches to design and manufacturing in order to lower costs and improve performance and quality. Funding would be about $50 million per year for five years.

• Increase Defense Department spending on research and development in semiconductor materials, devices, and manufacturing by about 25% a year over the course of four years. This increase will amount to about $60 million in the

ment of Defense and for the use of the SIA's existing research arm, Semiconductor Research Corp. (Research Triangle Park, N.C.), as the hub of the proposed consortium.

"The Sporck proposal is a viable idea," says VLSI Research's Hutcheson, "but the semiconductor companies are not known for working together. The problems lie not in the technology but in the practical difficulties of deciding who contributes how much and who gets to use the results of the development." Nevertheless, says George Scalise, senior vice-president of Advanced Micro Devices (Santa Clara, Cal.), "infighting between consortium members—and antitrust considerations—must be set aside" if the U.S. is to continue to make memory chips domestically.

The recent Defense Science Board report goes beyond the SIA proposal, calling on the government to subsidize the development, and possibly the manufacture, of 64-megabit DRAMs and other leading-edge ICs. Four-megabit memories are expected to appear well before the end of the decade, so the development of a 64-megabit RAM would be an attempt to "leapfrog" over both the 4M and the 16M stages. If the semiconductor industry cannot put together a suitable manufacturing consortium, the DSB recommends a government-owned production facility that would guarantee the Defense Department a steady supply of U.S.-made high-density DRAMs.

While U.S. proposals for joint ventures to compete with Japan are still in the discussion stage, things are moving in Europe: Philips and Siemens have had a joint project to develop 1- and 4-megabit DRAMs since 1984. Partly financed by the Dutch and West German governments, the $2 billion project is beginning to show results. Siemens has begun sample production of 1M DRAMs and expects to produce 4M devices by 1989. Philips is expected to begin sample production shortly.

These two companies, plus France's Thomson, are already moving toward very advanced technology with their Joint European Silicon Submicron Initiative (JESSI), says Hutcheson at VLSI Research. JESSI is aimed at developing manufacturing techniques for very dense integrated circuits, including DRAMs, with circuit lines less than 1 micron wide. The current manufacturing technology is generally based on 2-micron devices, but 4M and larger memory chips will require submicron technology. Thus the European DRAM manufacturers appear to be positioned at least to keep up with the Japanese.

Siemens, Philips, and Thomson have a common characteristic that sets them apart from the majority of U.S. semiconductor makers: they are diversified electronics companies that have internal, captive markets for their own semiconductors. They can therefore afford to develop memory chips, possibly at a loss, for inclusion in their own manufactured electronic products. In this way, the European companies parallel the giant Japanese

first year, growing to $250 million in the fourth year.

• Provide funds to the Pentagon's semiconductor suppliers for a healthy industrial R&D program related to DOD semiconductor needs. Cost: about $50 million a year.

• Establish a government–industry forum to assess the entire program and facilitate joint action on semiconductor matters relating to national defense.

TASK FORCE MEMBERS

Norman R. Augustine (chairman), president, Martin Marietta; Erich Bloch, director, National Science Foundation; Robert M. Burger, vice-president, Semiconductor Research Corp.; Malcolm R. Currie, president, Delco Electronics; Richard D. DeLauer, former undersecretary of defense for research and engineering; Jack S. Kilby, inventor of the IC; Gen. Robert T. Marsh, former commander of Air Force Systems Command; Walter E. Morrow, director, MIT Lincoln Laboratory; Lionel Olmer, former undersecretary of commerce; and Larry Sumney, president, Semiconductor Research Corp.

The report is available from the Office of the Undersecretary of Defense for Acquisition, Washington, DC 20301.

DSB task force's Larry Sumney, president of Semiconductor Research Corp.: "If the manufacturing consortium doesn't get under way in 1987, it may be useless to try."

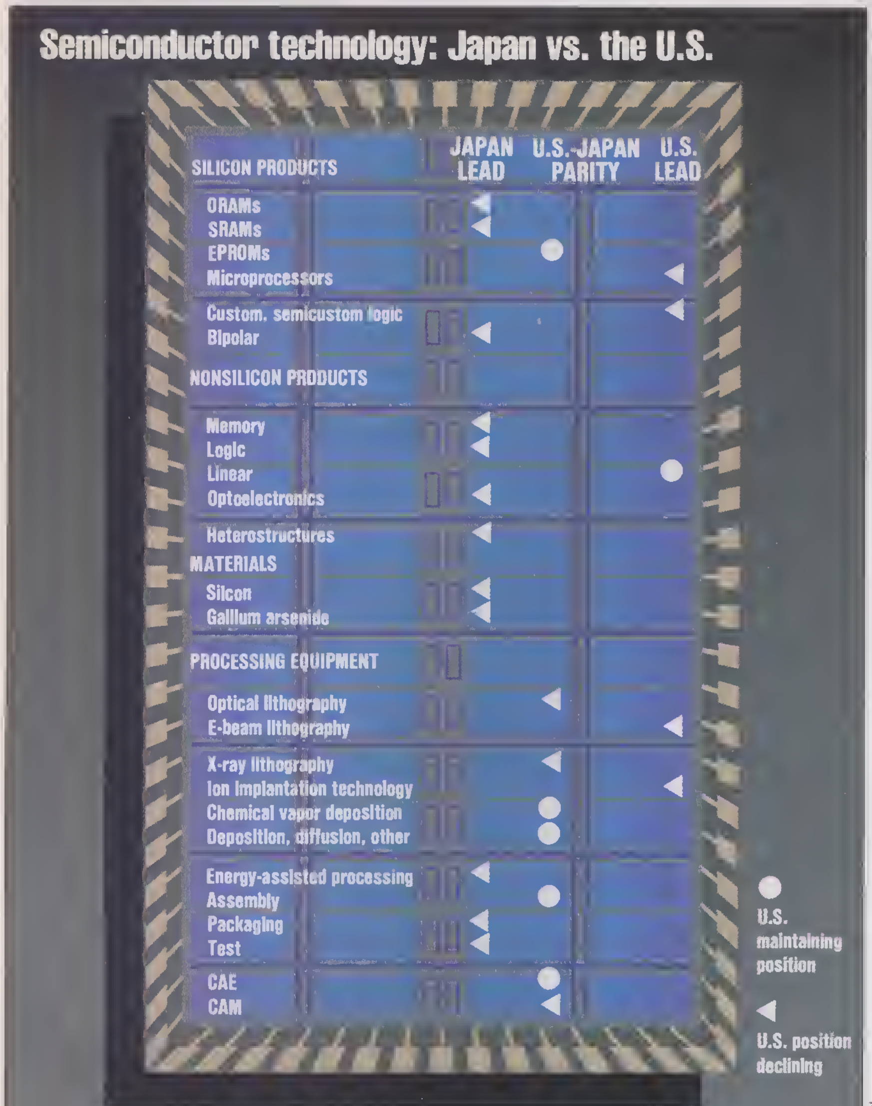
makers like NEC, Toshiba, Hitachi, and Fujitsu, which are often their own best customers for chips and can afford to subsidize their own memory production.

By contrast, similar diversified U.S. manufacturers, such as General Electric, are pulling out of the merchant semiconductor business, to the dismay of some observers. Unlike the Japanese, large U.S. companies often regard subsidiaries as independent profit centers, and so are less prepared to accept short-term losses. GE's Intersil subsidiary is rumored to be up for sale, and a number of Japanese electronics companies, notably Oki Electric, are thought to be interested in buying it.

One good reason for retaining American production of commodity chips is to help support domestic producers of semiconductor materials and manufacturing equipment. Even IBM—a highly successful manufacturer of memory chips—is participating actively in the SIA Sematech study partly out of a belief that American chip makers should buy their equipment from American suppliers. Without a strong domestic market for their equipment, says MIT's Ferguson, U.S. makers are unlikely to survive against the Japanese. Already, Japan has about 40% of the world market for semiconductor capital equipment. As a result, several U.S. equipment makers are suffering financially and may simply leave the business to the Japanese. Ironically, IBM's latest chip-making facility, the Advanced Semiconductor Technology Center (East Fishkill, N.Y.) is being built by Shimizu America, a subsidiary of a Japanese company. Losing the semiconductor equipment industry to the Japanese would force U.S. chip makers, whether merchant or captive to buy their production equipment overseas. In that case, the latest and most advanced equipment for making commodity ICs would probably become available to Japanese chipmakers first, further increasing their competitive advantage.

"We can now invest in ASICs, where volumes are low but profits are higher."

Only a handful of U.S. makers of semiconductor manufacturing equipment are managing to keep their heads above water. Perkin-Elmer (Norwalk, Conn.), for example, is turning a profit in this area, according to David Huchital, VP of the semiconductor equipment group; Perkin-Elmer has been an aggressive exporter and has received substantial support for equipment development under the Army's VHSIC (very-high-speed integrated circuit) program. More typical, however, is GCA Corp. (Bedford, Mass.), the biggest U.S. maker of optical lithography equipment, which almost went under last year because of the downturn in capital equipment orders for chip making and rapidly increasing competition from Nikon and Canon in both Japan and Europe.



In 25 areas of semiconductor design and production technology surveyed by the DSB task force on semiconductor dependency, the U.S. leads Japan in only five categories and is maintaining its position in only one, linear devices. Nowhere does the U.S. position appear to be improving against Japan's.

SOURCE: INTERAGENCY WORKING GROUP ON SEMICONDUCTOR TECHNOLOGY

IMAGE BUILDER DESIGN

According to reports from Japan, the giant trading house of Sumitomo is prepared to buy into GCA to help the company rehabilitate itself. And the optical lithography line of another maker, Eaton Corp. (San Jose), is idle and up for sale.

In an attempt to rescue the ailing semiconductor manufacturers that may be unable to make the investment in new equipment—whatever its source—for manufacturing submicron integrated circuits, the DSB report has recommended some $2 billion in Defense Department expenditures over five years. About half the money would be used to finance a memory chip manufacturing facility, possibly under the management of the SIA Sematech consortium. But this funding may be barely sufficient; a state-of-the-art semiconductor fabrication line probably costs $200 million today and might cost as much as $1 billion by 1995, according to industry experts.

For example, development of a synchrotron-based x-ray lithography system, needed for 16M and larger memories, might cost $400 million, according to Gwyn Williams, a researcher at Brookhaven National Laboratories (Upton, N.Y.). The Japanese Ministry of International Trade and Industry has already set up a consortium with 13 equipment makers to build a compact synchrotron for x-ray lithography (HIGH TECHNOLOGY, Nov. 1985, p. 11). Construction is expected to begin later this year.

DSB recommendations also include the expenditure of $50 million per year on setting up university-based Centers of Excellence in semiconductor science and engineering, and increased Defense Department spending on semiconductor R&D—from an additional $60 million in the first year to a $250 million boost in the fourth year of the plan.

The DSB report has still to be considered by the DOD, and a positive response is by no means assured. Several Washington observers say it is unlikely that large-scale funding from the Pentagon would be available during a time of tight budgets, and warn that the "window of opportunity" for the manufacture of 16-megabit DRAMs could easily be missed. "If the consortium doesn't get under way in 1987, it may be useless to try," says Larry Sumney, head of the SIA's Semiconductor Research Corp. and a member of both the DSB and SIA panels.

Many analysts feel that if the DSB report is not accepted and Sematech does not get off the ground quickly, the outlook for the U.S. semiconductor industry will be gloomy at best. "Within the next 18 months, much of the the U.S. semiconductor production will be directly or indirectly under Japanese control," says MIT's Ferguson. But others feel that leaving high-volume production to the Japanese is a necessary step for the U.S. chip makers. "We're better off letting the Japanese invest heavily in making chips with a small profit potential," says VLSI Research's Hutcheson. "We now have the opportunity to invest in ASICs, where volumes are lower but profits will be higher." Indeed, several chip makers, including Intel and TI, are opening design centers to bring proprietary computer-aided design methods to their customers for ASIC development.

Nor will the loss of memory production to Japan necessarily cause a lag in developing the most advanced production techniques. "DRAMs are no longer the technology driver," claims Billy L. Crowder, director of manufacturing research for IBM's T. J. Watson Research Center (Yorktown Heights, N.Y.). "Advanced logic and microprocessor designs will soon require submicron technology." The implication is that the dynamic U.S. computer industry will provide the incentives to develop leading-edge ICs and maintain a U.S. lead in complex chip design and manufacture—that the same vitality shown in the early days of Silicon Valley may bring about changes in the industry. Such changes, although painful in the short term, could not only assure survival but perhaps even drive a resurgence. □

Jeffrey Bairstow is a senior editor of HIGH TECHNOLOGY.

For further information see RESOURCES, *p. 61.*

Digital audio tape recorders that offer the same sound quality as compact discs plus recordability could have been in stores last fall. Yet they are being delayed by controversy—not about technology but about commerce.

So far, DAT technology belongs to Japanese audio companies only, and opposition stems from both the record and CD industries in the United States. Since DAT recorders make very high-quality digital copies from *any* audio source, record companies fear that they will encourage piracy. At the same time, CD makers fear that legitimately prerecorded DAT tapes, when they hit the retail stores, will undermine the CD market. Therefore these groups have proposed measures ranging from outright bans on DAT to putting mandatory copyright-protection circuitry in recorders. So far, DAT developers have resisted these pressures, but the arguments have been effective enough to postpone commercial introduction.

Officially, no introduction date for the U.S. has been announced by any of the dozen Japanese companies demonstrating DAT machines, although sales in Japan began in March. Dan Peterson, vice-president of Kenwood Electronics (U.S. headquarters in Carson, Cal.), says units could be available for shipment by early fall—if the industry agrees on a unified marketing plan. However, at least one manufacturer, Onkyo (Ramsey, N.J.), may not sell its machines in the U.S. at all if Congress passes proposed anticopying legislation restricting DAT, says product manager David Birch-Jones.

PORTABILITY IS KEY. In addition to boasting recordability, DAT will be more portable than CDs, which require 1-micron tracking precision for reliable playback and so must be played in vibration-free environments. While car and personal CD players are available, skipping and muting remain problems. And portability is still limited—a person can walk while listening to a personal CD player, but jogging is out.

Tape players, on the other hand, are much less sensitive to vibration. What's more, DAT cassettes are smaller than standard analog cassettes, permitting greater miniaturization: Walkman-like

THE DIGITAL CASSETTE VS. RED TAPE

Even if it overcomes opposition from the U.S. recording industry, the CD's rival is in for a tough market battle

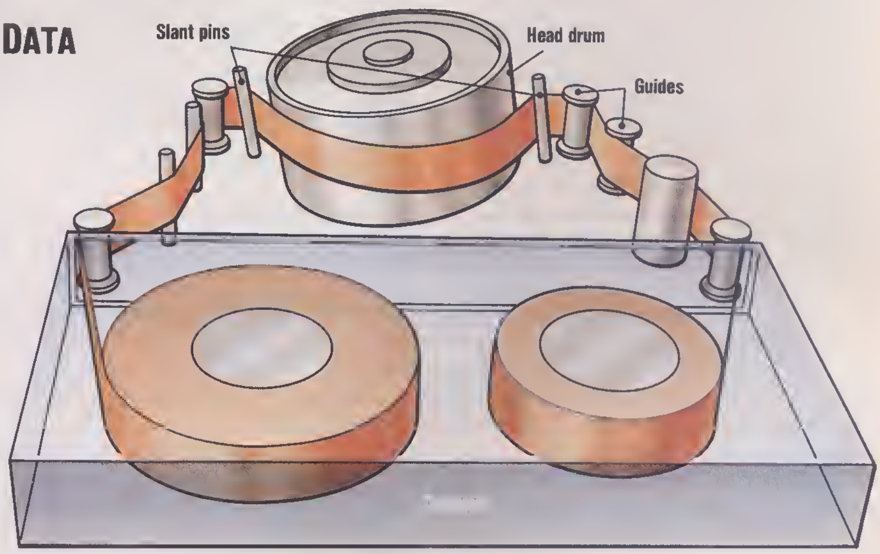
BY PETER W. MITCHELL

DAT players are expected to be only slightly bigger than a cigarette pack. Compact discs, meanwhile, are five inches across, and are vulnerable to fingerprints and scratches if not stored in their awkward "jewel-case" holders. This greater portability is what attracted the Japanese audio industry to the DAT concept: it fits in with the manufacturers' overall strategy of expanding the audio equipment market by developing products for mobile use.

Sample DAT tapes are being produced by TDK Electronics (U.S. headquarters in Port Washington, N.Y.), Fuji Photo Film (Elmsford, N.Y.), Sony (Park Ridge, N.J.), and Maxell (Moonachie, N.J.). Among the major manufacturers that exhibited prototype DAT recorders at last fall's Tokyo Audio Fair and at the January Consumer Electronics Show in Las Vegas were Onkyo, Sony (New York), Toshiba (Wayne, N.J.), Kenwood, Luxman (Torrance, Cal.), Teac (Montebello, Cal.), and Technics (Secaucus, N.J.). Also, Mitsubishi Electric (Cypress, Cal.), Alpine (Torrance, Cal.), and Clarion (Lawndale, Cal.) showed in-dash automobile players. Since there's not yet a catalog of prerecorded DAT tapes, play-only units for car and portable use will be marketed later than recorders, which allow buyers to make their own tapes from CDs, LPs, or live sources.

Manufacturers are currently using a "rotary-head" (R-DAT) system—a VCR mechanism in miniature. Two record/play heads are mounted on a drum that rotates at high speed, depositing parallel diagonal tracks on the tape as it moves slowly past. An alternative approach, the "stationary-head" (S-DAT) format uses a mechanism similar to a conventional analog cassette recorder, with the tape moving in a straight line past a fixed multitrack head that records 22 narrow data tracks in each tape direction (HIGH TECHNOLOGY, Jan. 1986, p. 56). During early development, S-DAT was considered essential for the "read-after-write" capability that professional users require; a second multitrack head reads data as it is laid down by the recording head, allowing recording engineers to listen for faults. Companies then developed read-after-write R-DAT systems that simply use a second pair of heads on the same rotating drum. Development of the more expen-

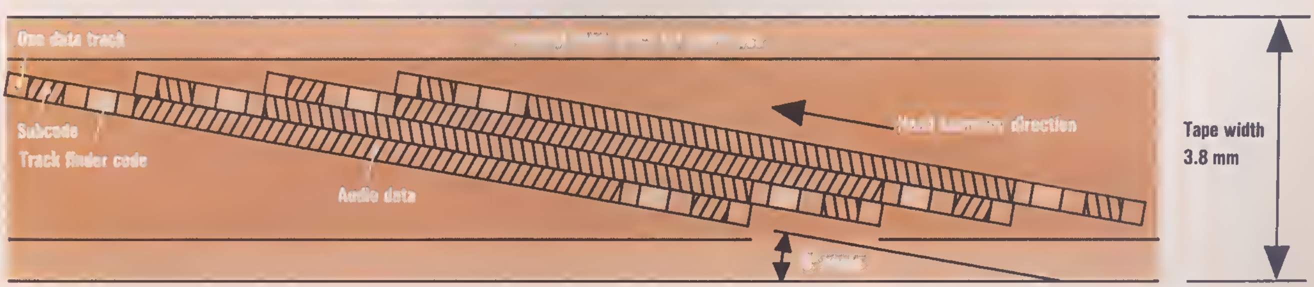
A LITTLE DAT HOLDS A LOT OF DATA



A digital audio tape deck must record or play a tremendous amount of data in a very short time—2½ million bits of code for sound signals and error correction each second. To fit all this code on a tape just 3.8 millimeters wide, DAT manufacturers essentially borrowed technology used in 8-mm videocassette recorders, shrunk to half the size. The key is record/playback heads that move very quickly in relation to tape speed, thereby compressing data bits onto a smaller surface area of the tape. To do this, the two DAT record/pickup heads are mounted on opposite sides of a spinning drum. During operation a length of tape is wrapped partially around the drum, which is tilted 6°. Thus, as the drum spins at 2000 rpm, the two recording heads, one after the other, track diagonally across the tape, leaving parallel data tracks as the tape moves past at a rate of only 0.32 inch per second.

For further space saving, the 13-micron-wide diagonal tracks are laid down with no gap between them. That could make reading difficult; while following one data track, a head could pick up interference from adjacent tracks. To prevent this, the two heads are tilted so that the data-code bars in each successive track slant at a different angle from the bars in the preceding track, forming a herringbone pattern. As a result, when a head reads a track during playback, adjacent tracks are effectively invisible since their magnetic pattern is at the wrong angle.

To leave room on each track for nonaudio data, the music signal is laid down in compressed bursts of 5 milliseconds for each 15 milliseconds of actual sound. (During playback the sound signal is first stored in a buffer memory, then released by a quartz clocking mechanism that reconstructs a continuous analog signal.) This leaves room on each track, before and after the 5-millisecond burst, for recording automatic track-finding (ATF) signals, which align each head with the proper track, and subcodes, which record information such as selection numbers. DAT has capacity for about four times as much subcode data as CD; it could even be used for digitized video still-frame sequences, with the picture changing every few seconds. Also, fragments of the subcodes can be read while the tape is being fast-wound (at 300 times normal playing speed), enabling the DAT player to be cued to any point on the tape within 36 seconds.



ILLUSTRATIONS BY MARK ALSOP

sive S-DAT format has therefore been moved to the back burner. Nevertheless, JVC has stated plans to market an S-DAT machine within a couple of years

SCUTTLING PIRATES. To deter direct digital copying of compact discs, DAT developers changed the units' digital sampling rate; originally it was identical to CD's rate of 44.1 kilohertz (the audio signal is sampled 44,100 times per second, each sample being converted to a digital value). Since identical rates would allow digital-to-digital taping of CDs, thereby encouraging illicit copiers, designers are restricting the 44.1 kHz recording rate to professional DAT recorders and duplicators, making them compatible with existing recording studio equipment. (So far, only Sony has officially announced plans to sell a professional model.) Consumer DAT units will record at 48 kHz (or optionally at 32 kHz) and will use 44.1 kHz only for playing professionally prerecorded tapes.

Further copy protection could be built into each CD, using the discs' subcodes (nonaudio reference data such as song selection number). Discs could be encoded with copy-protect "flags" that would instruct specially designed DAT machines to drop out of recording mode. Of course, this would require the cooperation of DAT manufacturers, who would have to program their recorders to recognize the flag. So far, the industry has resisted such measures, on the grounds that they would limit DAT's versatility.

In any case, neither of these obstacles is foolproof. To get around incompatible sampling rates, large-scale commercial pirates could use sampling-rate converters to restore direct digital copying from CDs. And at home, where CDs would have to be recorded via the disc player's analog output jack, the resulting loss of sound quality would be so slight as to go virtually unnoticed. As for copy-protect flags in CD subcodes, they would prevent only direct digital-to-digital dubbing.

To prevent *all* copying, therefore, the Recording Industry Association of America (RIAA), the International Federation of Phonogram and Videogram Producers (IFPI), and the Motion Picture Association of America (MPAA) are rallying behind a CBS Records proposal to put an inaudible sonic "fingerprint" on all records and CDs; DAT recorders sold in the U.S. would have to be outfitted with special circuits to scan for any output at the 3.8-kHz frequency, which would have been removed from a CD or LP during recording. If it was lacking, the circuit would shut down the DAT recorder. (To prevent errors—like disabling the recorder for noncopyrighted music that just happened to have no output at 3.8 kHz—the circuit would also monitor a wider frequency band that included 3.8 kHz. If there were no output in the entire band, the recorder would continue to operate.) A DAT owner could still record speech, live music, or old, unfingerprinted recordings.

But an objection to such fingerprinting is that it's not really inaudible. Sensitive listeners say that the omission degrades fidelity, altering the timbre of some musical sounds—violins and soprano voices, for instance, which are likely to have harmonics at the filtered frequency. They argue that the whole point of technical advances like digital recording is to improve fidelity. Thus deliberate degradation by the record industry might even discourage serious listeners from buying some recordings.

Also, the anticopying circuit would block recording activities that the U.S. Supreme Court has already declared legal. Under current law a consumer is permitted to make copies of any purchased recording or public broadcast for personal use. Nevertheless, legislation restricting DAT is currently under consideration by Congress. Making its way through the Senate, bill S.506 would require DAT manufacturers to incorporate anticopy chips that recognize the 3.8-kHz fingerprint, or face a stiff tariff. House bill H.1384 seeks to ban DAT altogether.

DAT's chief advantage at the moment is its recordability, but erasable CD technology is under development.

A COMPETITIVE STRUGGLE. In the absence of unilateral action by Japanese DAT makers or of protective federal legislation, the battle between DAT and CD will likely be waged in the marketplace. And despite DAT's advantages, its dominance is by no means assured. For example, while reasonably quick random access of DAT selections is provided via indexing and track-finding systems that permit listeners to select songs in any order, CD is still faster. And while a single DAT cassette can hold two hours of music versus CD's capacity of 75 minutes, this benefit will probably apply to homemade cassettes only; prerecorded DAT tapes will probably contain the same music as the equivalent CD release.

Meanwhile, after nearly four years on the market, CD technology has a good reputation that has earned it some momentum. According to projections by the Electronic Industries Association (Washington, D.C.), as many as 4 million CD players will be sold in 1987, and CBS Records (New York) forecasts disc sales of 250 million. And in response to growing demand, a dozen new CD pressing plants are scheduled to open this year, doubling worldwide pressing capacity. In Kings Mountain, N.C., Philips/DuPont Optical is preparing to open a plant with an initial annual capacity of 10 million discs, expected to expand to anywhere from 50 to 100 million, making it the largest in the United States. Another large CD pressing operation is under construction in Alabama by Warner-Electra-Atlantic.

Thousands of CD recordings are currently available, but the repertoire wasn't built overnight. It would probably take DAT producers several years to amass a satisfying stock of prerecorded cassettes. Furthermore, resistance by the recording industry may retard the availability of prerecorded DAT; both CBS and Polygram International have stated that they will not market DAT recordings.

With regard to cost, CD comes out on top, at least in the short term. Many disc players now sell for under $200, and a few models are even approaching the $100 level. According to consultant Marc Finer of Communication Research (Pittsburgh), first-generation DAT machines launched in Japan in March average $1200. Therefore, as long as the dollar/yen exchange rate stays at current levels, it seems certain that DAT machines will sell for more than $1000 in the United States. And since DAT technology is already relatively mature—relying on very-large-scale integrated circuits—it may not see the sizable price reductions that occurred when other electronic product types were simplified through computer chip advancements.

Individual compact discs currently retail for about $12 to $15, but Sony is developing a DAT printer that the company expects will be able to turn out prerecorded DAT cassettes at much lower cost. The Sony system—a form of magnetic contact printing—places master tape and blank tape face to face under pressure as they pass through a magnetic field, transferring the magnetic pattern of the master onto the duplicate. Sony claims that this allows an 80-minute tape to be copied in about five minutes.

But initially, prerecorded digital tapes, produced by older methods, will probably cost more than CDs. Even blank DAT cas-

KEN KERBS

Onkyo's David Birch-Jones says that if anticopying regulations are enacted, his company may abandon hopes of selling DAT in the U.S.

settes will be expensive at first—perhaps as high as $15—reflecting low production levels and high development and equipment costs.

In the meantime, CD makers aim to lower the price of recordings through improved production technology before lower-cost DAT cassettes are available. Vox, a division of Moss Music Group (New York) has already cut the price of its "Prima" CDs to below $10, partly by devising a cardboard package to replace the more costly jewel case. And other companies in Japan, Europe, and the U.S. are researching ways to produce CDs quicker and less expensively.

For instance, a new "direct metal mastering" process from West Germany's Teldec may halve the cost of making the stampers that mold CDs, the company claims. In the conventional process, a laser exposes a light-sensitive coating on the master disc, which is then "developed" so that the exposed spots dissolve away, leaving pits that represent the data points to be read by the CD player. Since data errors can be introduced by dust particles, costly cleanroom conditions must be maintained at CD mastering plants. Teldec eliminates the photographic process and its cleanroom requirement by using a piezoelectric stylus to create the pits directly in the surface of master discs coated with copper. Many CD pressing stampers are then molded from the copper-clad master.

To reduce the high reject rates at CD plants, General Electric, a major supplier of the polycarbonate plastic used in the discs, has developed a modified molding cycle that eliminates "birefringence" (strain marks formed as the plastic cools). Recognizing that the stress marks are caused as the cooling plastic shrinks and pulls away from the mold, GE increases the pressure on the mold a few seconds after the material is injected—in effect reducing mold thickness to compensate for the shrinking plastic.

Another way to improve CD production levels, and thus reduce cost, is to employ a high-speed CD pressing process. Such a method, being developed by DOCdisc in the Netherlands, uses a version of the DOCdata rotary microprinter to "press" the pits in CD blanks. The technique promises to turn out CDs at a rate of one per second instead of one every 25 seconds, as with injection molding.

While such advances will improve the competitiveness of CDs against prerecorded digital audio tapes, they won't address DAT's possibly overwhelming advantage over discs: recordability. Strong evidence suggests that consumers prefer a medium that can make its own recordings; the VCR is vastly more popular than the videodisc player, and cassette players outsell LP turntables. While it's reasonable to assume that buyers will show the same preference for DAT over compact discs, the home-recordable CD will probably be on the horizon by the time DAT machines and tapes become both inexpensive and popular. Matsushita (Osaka, Japan), 3M (Minneapolis, Minn.), Philips (Baarn, the Netherlands), and other companies are preparing commercial versions of WORM (write once, read many) CDs that will be used mainly for computer data storage. However, the technology is expected to evolve into erasable audio CDs, probably in five years or more. Despite all the present debate, that's the time when the battle may really begin. □

Peter W. Mitchell is a recording and product design engineer who writes about audio, video, and computers.

For further information see **RESOURCES**, *p. 61.*

Dean Baker holds Northrop's "focal plane array" infrared detector, used in a telescopic TV camera (foreground) for the Navy's F-14 Tomcat fighter.

SALLY ARISTA

PENTAGON SEES INFRARED

Advanced sensors will provide greater accuracy in surveillance and target recognition

BY SALVATORE SALAMONE

Infrared detectors could play a major role in surveillance and target recognition, but the images produced by existing IR devices do not show enough detail to identify targets reliably. The Department of Defense (DOD) is therefore planning a major program—with a 1988 budget estimated at around $500 million—to speed up the development and acquisition of new infrared detectors.

The first step in satisfying the military's needs has just been met with the development of dense arrays of sensors called focal plane arrays. Other advances include more signal processing right on the sensor chip and a move to sensors that operate at different IR wavelengths from the current detectors. Several major U.S. electronics suppliers—among them Ford Aerospace (Newport Beach, Cal.), Hughes Aircraft (El Segundo, Cal.), Northrop (Anaheim, Cal.), and Texas Instruments (Dallas)—are competing for DOD contracts to build the new detectors.

The main military appeal of IR systems is that they emit no signals of their own. This is important because developments in electronic countermeasures and radiation-seeking missiles have made active systems like radar less desirable. In fact, Donald N. Fredrickson, deputy undersecretary of defense, believes that in 10 years "if you radiate, you may be dead in a few minutes."

The IR systems work by sensing heat emitted by their targets. Thus planes and land vehicles that are not emitting a detectable radar signal, or that are actively jamming in the radio-frequency range, can be detected. Even aircraft equipped with stealth technology, which makes them almost undetectable by radar, will not entirely evade IR sensors.

IR detectors aren't new. The Air Force uses sensors designed to help pilots seek out and destroy targets at night and in adverse weather, while flying at low altitudes to avoid enemy defenses. The Marines use similar devices with helicopters to accomplish the same thing. The Army has developed IR systems to help identify tanks and other ground vehicles, while the Navy is using such devices on its fighters. Because of the limited resolution, however, an operator cannot tell whether a particular splotch on the screen represents a tank or a small building.

The new IR night-vision systems, by contrast, produce "daylike" pictures so clear that individual vehicles, such as fighters on an airfield, whose IR emissions differ from those of their surroundings, can be identified. Furthermore, the detectors are small and light enough to fit comfortably into cramped fighters.

IR systems for day vision, meanwhile, are aiding visible-light telescopes in identifying aircraft and other targets at greater distances; such targets appear brighter in the IR than in visible light. "We have done detection and tracking on commercial aircraft well over 100 kilometers away," reports W. Dean Baker, vice-president of engineering at Northrop's Electro-Mechanical Division. An extension of these capabilities now under development is automatic target recognition (ATR), which uses artificial intelligence not only to spot a vehicle or aircraft but also to identify its type.

IR detectors could also be of value in the Strategic Defense Initiative by providing early warning and tracking of ballistic missiles. Based in orbit, the detectors would scan large areas beneath them, updating the IR images of individual missiles every few hundred milliseconds, and then search for exhaust plumes emitted by missiles in the first few minutes after launch. (And here the environment provides some help: because the atmosphere thins out as altitude increases, the exhaust plumes of ascending missiles become more detectable.)

All objects on the earth and in orbit around it emit strong IR signals. While water vapor in the atmosphere absorbs some of this energy, enough generally remains to be picked up by detectors that are designed to respond in one of three major bands of infrared radiation: short wave (1–3 microns); medium wave (3–5 microns), the most common target for detectors; and long wave (8–14 microns). Radiation in the 5–8-micron band is absorbed by water vapor in the atmosphere.

The wavelength of radiation emitted by any object depends on the object's temperature. Hence, short- and medium-wave IR detectors can identify targets that appear "hot" against a cold background, such as an aircraft whose emitted engine heat stands out against the cold sky. But space-based detection of a "cool" missile against the warmer background of earth below it demands a long-wave detector.

At the heart of IR detection is the individual sensor, a square cell a thousandth of an inch on a side, which converts the energy of infrared light striking it into electrical signals. A photolithographically produced chip containing thousands of such cells, called a focal plane array (FPA), provides signals that can subsequently be processed into television-like images. Because of the large number of cells, an FPA can view an entire scene instantaneously—unlike current systems, which must use moving mirrors that reflect one part of the scene at a time onto the detector. What's more, FPAs contain multiplexers, which mix the signals from the individual detectors, allowing signal processing to be done right on the chip.

In theory, an enormous number of sensors can be linked together in this way. "The main limitation is yield and not the electronics," explains Baker at Northrop, which already sells FPAs containing more than 64,000 detectors. The yield drops as circuit density on the chip increases. The current pilot line produces yields of 10% for the 128 × 128 arrays.

Optimizing detection involves several requirements, some of which conflict. To obtain the best resolution, designers use the smallest individual sensors possible. To improve sensitivity, they group together as many sensors as they can. And to enable them to decipher the comparatively weak IR signals from the sensor's own background noise, which increases with rising temperature, they keep the sensors as cold as possible. To achieve the minimum practical temperature of 77° Kelvin—the boiling point of liquid nitrogen—the sensors are sealed in a Dewar flask containing that element.

Space-based IR starers will be used to provide early warning and tracking of ballistic missiles.

In conventional IR devices, every sensor is connected to an amplifier by its own wire, and each wire has to pass through a small opening in the lid of the Dewar. The greater the number of openings, the greater the amount of coolant that leaks out. This problem limits the number of individual detectors one can put in a Dewar to a few hundred. FPA chips (with the signal processing done right on the chip), by contrast, need only a couple of wires through the Dewar lid. This extends the time the device can be used before the coolant needs to be refilled.

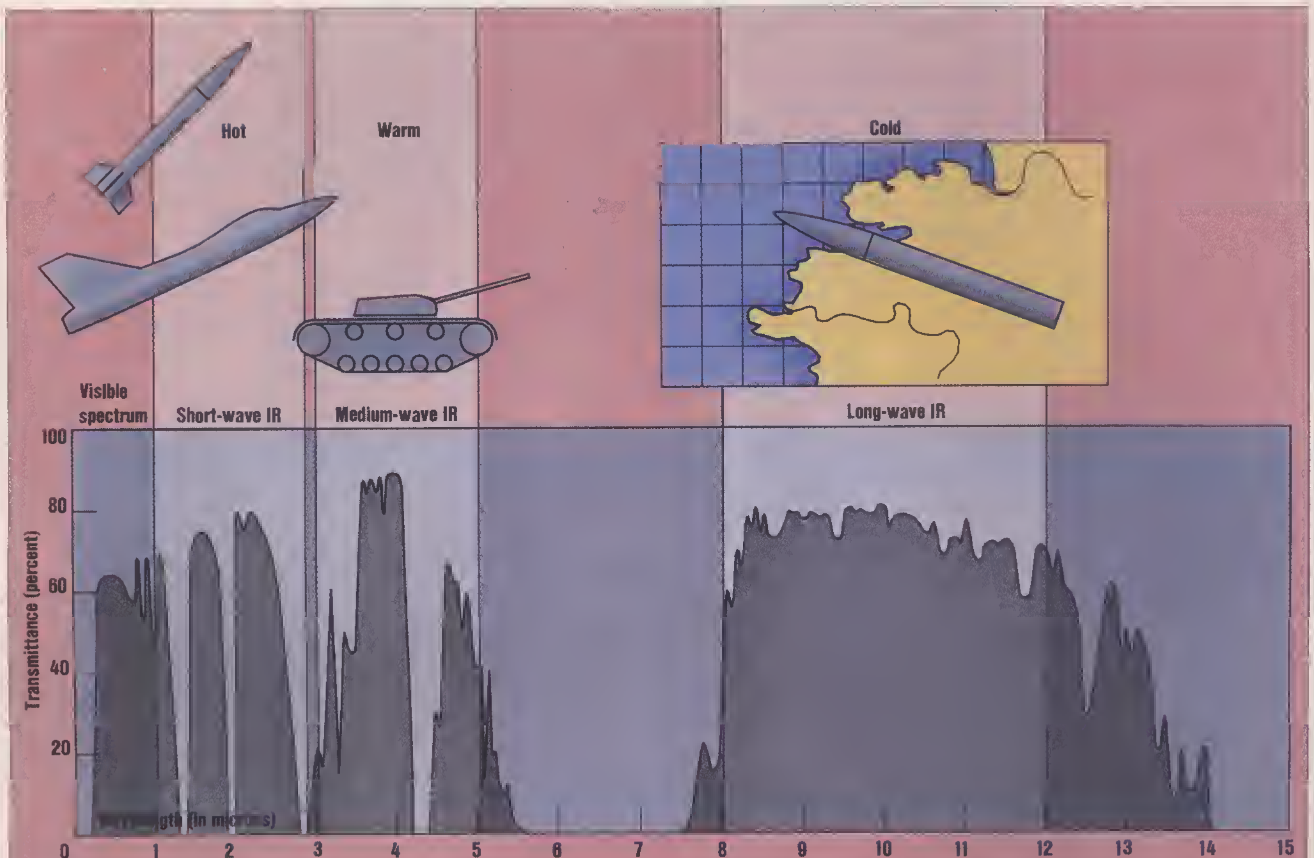
In addition to cramming more sensors on a chip, researchers are looking for materials that result in more versatile detectors. Northrop and General Electric (Schenectady, N.Y.) use sensors made of indium antimonide (InSb), whose purity and uniformity achieve the greatest sensitivity and resolution in the 2–6-micron range. Unfortunately, InSb detectors do not work beyond that band, but several companies are examining alternative materials to extend detection.

Sensors of mercury cadmium telluride (HgCdTe), for example, work in all three IR bands; a device can be tuned to the low, medium, or high band by varying the concentrations of mercury and cadmium in the detector chip during its manufacture. Texas Instruments is studying a single HgCdTe detector that works simultaneously in both the medium- and long-wave IR regions, a property that provides remarkable sensing flexibility. The major disadvantage is that yields are reportedly as low as 1%.

Another compound offering unique advantages is platinum silicide (PtSi). The General Motors/Hughes Electronics Missile Group (Canoga Park, Cal.) has incorporated a chip containing 65,536 such sensors into an FPA for the Army's proposed fiber optic guided missile (FOG-M) system. PtSi benefits from the mature silicon manufacturing technology. That means high yields, since the detectors can be made on four-inch wafers (HgCdTe detectors can only be made on two-inch wafers), thereby enabling four times as many chips to be manufactured at a time.

Knowing that IR energy passes through the silicon substrate on which PtSi sensors are made, designers at Hughes Aircraft have been able to simplify the detectors' design by bonding sensor chips directly to multiplexing and signal processing chips. This eliminates the connections normally required, and that saves money. Freeman Shepherd, chief of the Rome Air Development Center's Electronic Devices Technology Division (Hanscom Air Force Base, Mass.) and the developer of PtSi detectors, estimates that the sensor could be produced at one-twentieth the cost of those made with other materials. Low cost is an important consideration in missile sensors, which are throwaway items in far greater demand than multiple-use aircraft sensors, says Robert Aguilera, who manages the Hughes sensor program.

The promise of two other substances has not yet been realized. Lead sulfide and lead selenide have been made into detectors that can operate at room temperature, thereby eliminating the need for refrigeration units. The saving in weight and volume should make these detectors ideal for use in fighter aircraft. However, David Pollock, director of advanced electro-optical systems for ITT's Avionics Division (Nutley, N.J.), points out that cryogenic detectors are 1000 times as sensitive as the room-temperature detectors now available

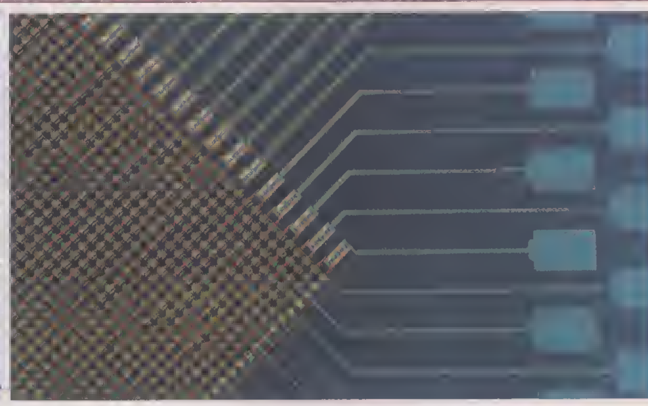


Each IR band detects objects at different temperatures. Short-wave (1–3 microns) can find hot exhaust plumes, medium-wave (3–5 microns) is good for warm ground-based objects like tanks, and long-wave (8–14 microns) can find cool free-falling missiles against the warm earth as viewed from space. Infrared energy with a wavelength of 5–8 microns has zero transmittance—that is, it's absorbed by water vapor in the atmosphere.

MARK ALSOP

COMBAT ARMS INTERNATIONAL MAGAZINE

A tank is easily identified from the air with Martin Marietta's targeting pod.



Sensors in Northrop's focal plane array, each a thousandth of an inch on a side, are arranged in a 128 × 128 pattern.

and that improvements on the drawing board should maintain their lead.

A small FPA detector made from InSb sensors by Northrop's Electro-Mechanical Division shows that cryogenic devices can meet strict requirements for weight and volume. Designed for tactical aircraft too small to carry the cumbersome refrigeration units of current night-vision devices, the FPA has 16,384 sensors, each about one-thousandth of an inch square. The IR energy that they absorb is processed and converted into a television picture displayed on a cockpit monitor. The device achieved an industry first in 1986, recognizing targets at classified distances in excess of 10 miles. It will operate in conjunction with the television camera on the Navy's F-14 Tomcat fighter, and work as a tracking adjunct system for the Army and Marine Corps Hawk antiaircraft missile. In both cases, it will extend daylight vision to 10 times the range of the unaided eye. Says one Navy officer, "Adding the daytime IR system is the most important tactical modification on the F-14."

Another major program is the Low-Altitude Navigation and Targeting IR for Night (LANTIRN) cockpit display system being produced by Martin Marietta (Orlando) for the Air Force's Aeronautical Systems Division (Wright-Patterson Air Force Base, Ohio). Intended for the McDonnell Douglas F-15E Strike Eagle and the General Dynamics F-16C/D aircraft, the system consists of two separate pods (for navigation

Hughes's Aguilera, with low-cost IR seeker for the Army's Missile Command.

John Perkins of Hughes, with night vision pod developed for the Navy's F/A-18 Hornet fighters.

and targeting) attached to the underside of the aircraft.

LANTIRN will enable planes to fly at high speeds close to the ground, making them less detectable to enemy forces. The navigation pod contains a terrain-following radar that allows the pilot to fly below 500 feet at night, along with a wide-field-of-view forward-looking IR (FLIR) system that produces near-daylight images on a head-up display. In tests of the pod, aircraft flew night missions at altitudes as low as 100 feet at 550 mph. In daylight conditions, the system can detect and identify camouflaged targets such as tanks that have recently moved into position and are still warmer than the debris used to hide them. Another feature of the targeting pod allows the pilot to find and track targets on the ground from several miles away. After identifying the target, the pilot marks it on the head-up display with a laser designator; a laser-guided bomb is then automatically delivered to that target.

Whereas current detectors simply spot targets, FLIR systems such as LANTIRN provide three levels of identification: detection; recognition of the target—say, a small jet fighter; and images so detailed that, when the fighter gets closer, a MiG can be distinguished from a similarly sized U.S. aircraft. The image produced by a FLIR is divided into squares called pixels. Detection occurs when a target shows up in a single pixel. For a pilot to recognize the target as a particular type of aircraft, its image on the display must cover about 6–8 pixels, while 12–14 pixels are needed to distinguish friend from foe. The size of the pixels depends on the size of the individual IR sensors; only in the past two years have sensors become small enough to make the third level of identification possible.

One disadvantage of FLIR systems is that the pilot must wait for the image to reach a certain size before he can identify it and take appropriate action. With LANTIRN FLIR, a 20-foot object can be detected about 28 miles away, recognized by type 7 miles away, and identified 3 miles away, which can be dangerously close in combat. Another problem is that FLIR alone cannot give an accurate range to a target. Estimates of range, however, are possible with some knowledge of the target. Pilots of reconnaissance aircraft probing the Russian border, for example, would generally know what type of interceptor is usually dispatched in these circumstances. They can thus estimate the range from the size of the image on their display screens.

In a similar application, Hughes Aircraft's Electro-Optical and Data Systems Group has received a 30-month contract from McDonnell Aircraft to develop the Thermal Imaging Navigation Set (TINS) to be used on the Navy's F/A-18 Hornet fighters. TINS will provide pilots with daylight-quality images of the terrain ahead, allowing high-speed, low-altitude attacks on ground targets in darkness, smoke, or haze.

Originally developed for airplanes, the new infrared detectors are now being adapted for other types of vehicles. The Amber program, jointly sponsored by the Defense Advanced Research Projects Agency, the Army, and the Navy to develop a remotely piloted vehicle that can stay in flight for several days, will contain FLIR systems to improve its target surveillance. The Honeywell Electro-Optics Division (Lexington, Mass.) has received a $6.7 million contract from Agusta of Italy to supply a Helicopter Infrared Navigation System (HIRNS) for the Mangusta A129 Helicopter; HIRNS couples a FLIR system with an Integrated Helmet and Display Sighting System, supplied by Honeywell's Military Avionics Division (Minneapolis), to project the infrared image onto special goggles worn by the pilot.

The new infrared systems are also finding civilian application. For example, Hughes has installed a night-vision system on U.S. Customs Service Piper Cheyennes to patrol U.S. borders for drug smugglers. And Keystone Helicopter Corp. (West Chester, Pa.) has installed Texas Instruments FLIRs on Bell Long Ranger helicopters used by the Delaware State Police in searches for fugitives and lost persons. Crews can operate as high as 1000 feet instead of at the more dangerous 200-foot altitude needed in a spotlight search.

Nevertheless, the main developments in IR detection concern military surveillance. The improved resolution and sensitivity that allow IR sensors to detect a target at greater distances, along with the detectors' passive nature, which "hides" the observer, seem to make an unbeatable combination. But no new method of detecting military targets lasts long without the development of technical means to counter it. In fact, research has already begun on ways to offset the IR systems. One project, being conducted by Piaggio (Italy), seeks ways to shift engines' IR emissions to undetectable wavelengths by using special coatings and by mixing the hot exhaust with cool air. Another possible countermeasure is the use of lasers to "blind" the detectors. For that to work, however, the narrow laser beam must make a direct hit on the small IR sensor at great distances.

IR detection technology has a head start over efforts to neutralize it. For the next several years, at least, it will likely continue to stay well ahead of the countermeasures. □

Salvatore Salamone is an associate editor of HIGH TECHNOLOGY.

For further information see RESOURCES, *p. 61.*

THE MILITARY DRAWS A BEAD ON ELECTROMAGNETIC GUNS

Reacting to the fear that NATO land forces in Europe might one day have to fight the vast tank armies of the Soviet bloc, the Defense Advanced Research Projects Agency (DARPA) is sponsoring development of advanced tank technology to offset the West's numerical inferiority. High on the priorities list are electromagnetic tank guns that offer muzzle velocities considerably higher than those of conventional ammunition used by old-style Soviet tanks. Effective ranges of 5 and even 10 kilometers are possible with electromagnetic guns, instead of just 2 kilometers or less for present-day ordnance.

Conventional guns, which rely on the energy of self-contained chemical explosions to accelerate rounds of ammunition, typically fire their shots at muzzle velocities of about 1½ kilometers per second. By contrast, electromagnetic guns are driven by externally applied discharges of electromagnetic energy. LTV Aerospace (Dallas) has set a record by firing 2½-gram plastic cubes at speeds of up to 8.6 km/sec. The Strategic Defense Initiative Organization has more ambitious goals, sponsoring research on space-based electromagnetic weapons to fire small intercepting missiles at up to 25 km/sec. The DARPA project is more down-to-earth, aiming at velocities of 2½–4 km/sec, which appear possible with near-term technologies.

DARPA's goals are to build single-shot electromagnetic guns that can soon yield laboratory data, and to develop multishot guns with self-contained power supplies able to fire 10 rounds in three minutes. The DARPA program, which started last August, has two phases. The first, lasting 30 months, features contract awards of $30 million each to Maxwell Laboratories (San Diego), FMC Corp. (Santa Clara, Cal.), and the University of Texas (Austin) Center for Electromechanics, and an award of $8½ million to EML Research (Cambridge, Mass.). Each contractor will develop a complete system, including power supply and gun. This phase will end in March 1989 with a "shoot-out"—a competitive evaluation of the designs. Another 30-month phase will follow, ending in a second evaluation late in 1991. Here the electromagnetic guns will be fired alongside their chemical counterparts, in a series of Army tests that will determine the next generation of field ordnance.

by T. A. Heppenheimer

Electromagnetic guns have several major elements: the gun barrel, the power source, the energy storage and switch, and the projectiles themselves. Possible gun barrels include railguns, coilguns, and electrothermal guns. The railgun has received the most attention, having been studied at Westinghouse (Pittsburgh), GA Technologies (San Diego), LTV Aerospace, and the University of Texas. It consists of two parallel rails, with a projectile riding between them and a metal foil at its rear. When electric current surges up one rail, across the foil, and back down the second rail, it vaporizes the foil and produces a plasma (hot ionized gas). It also generates strong magnetic fields around the rails. The interaction of these fields with the current through the plasma then produces a strong acceleration, thrusting the plasma forward and thus firing the projectile.

Electromagnetic guns' long range could offset the West's numerical inferiority in Europe.

The railgun's simplicity is countered by two major disadvantages, however. Because most of the energy is lost in heating the rails, the gun's electrical efficiency rarely exceeds 10–15%. Moreover, railguns demand millions of amperes, a current that is hard to handle with existing electrical switches.

The coilgun, under development at EML Research, may overcome these difficulties. It features an array of electrical coils stacked like a roll of Life Savers to form a tube. The projectile also carries a coil, in its base. As it races down the tube, this coil triggers electrical contacts that feed energy to the barrel's coils in succession. This produces a magnetic wave that speeds behind the projectile, keeping pace with it and imparting an acceleration of 50,000 g's or more. The use of multiple coils reduces the required current from millions to hundreds of thousands of amps, while boosting the electrical efficiency to the 50% range.

The electrothermal gun, under development at GT Devices (Arlington, Va.), is a hybrid of electrical technology and conventional gun barrels. The projectile is accelerated by an expanding gas, as is the case with chemical munitions. There are, however, several important differences. To vaporize the propellant, the electrothermal gun uses an electric discharge that can be maintained in the gas as the projectile moves the length of the barrel. This keeps the gas hot, giving the projectile a more vigorous push than chemical-explosion gases, which cool off as they expand within the gun barrel. Also, because the chemical composition of the propellant used in the electrothermal gun has a much lower molecular weight than that used in conventional munitions, the gases given off as the propellant vaporizes move at a higher velocity, producing more thrust and sending the projectile down the barrel faster. This approach has not been selected for DARPA's program, but it remains a candidate for future work.

Power sources also come in several varieties. One type is a generator consisting of a heavy flywheel spinning in a magnetic field (called a homopolar generator). The energy stored in the rotating wheel is tapped when the switch to the gun is opened; electrical brushes fall across the wheel, completing the circuit. This transfer of energy into the gun rapidly decelerates the flywheel, however, producing a substantial torque. Thus, although they are frequently used in laboratory research, homopolar generators may prove difficult to adapt to a field weapon: the sudden torque could cause the projectile to go off course and even cause steering problems in the tank. Another problem is that the brushes do not easily stand up to millions of amps of current. More serious still, opening switches have had to be replaced after each shot.

As an alternative, the University of Texas has developed the compensated pulsed alternator, or compulsator—a rotating electrical generator that produces

pulses of alternating current. It requires neither a coil for energy storage nor an opening switch. Control of timing enables the projectile entering the gun to close an electrical contact and tap precisely one pulse from the compulsator; the pulse cuts off as the projectile leaves the barrel, saving energy and preventing the formation of a strong electrical arc across the end of the barrel. The University of Texas is utilizing developments at Oak Ridge National Laboratory to create a lightweight system that uses graphite-epoxy composites (instead of iron) for all structural parts that do not carry electricity. It will weigh 6 tons—low for a compulsator—and produce 4.4-million-amp pulses.

Another power source that reduces the use of iron is EML's "multidisc alternator." Its inventor, Henry Kolm, claims that it can produce 170 kilowatts per kilogram of mass, some 70 times better than the lightweight alternators used on aircraft. Such alternators are made mostly of iron, with only about 2% of their weight being current-carrying conductors. But Kolm's new alternator is 70% conductor by weight. The design is proprietary but Kolm expects to release details once his patent is issued. While it needs no brushes, it does require an opening switch. Kolm uses temperature-resistant carbides to produce a variable resistance that rapidly decreases as the switch opens. In tests sponsored by the Army, this switch has successfully handled currents of up to 760,000 amps.

Besides research into power sources, the DARPA program is investigating more efficient means of energy storage. Maxwell Labs is developing vastly improved capacitors, which can store energy in electric fields. This approach has traditionally been regarded as inefficient, since capacitors typically store much less energy, weight for weight, than can be stored in flywheel-driven generators. But the Defense Nuclear Agency has used the energy from discharges of capacitors to produce bursts of x-rays to simulate the effects of a nuclear explosion on electronics equipment. The agency is supporting research at Maxwell Labs in hope of improving the energy storage of capacitors 500-fold.

A capacitor amounts to a stack of aluminum foils interleaved with sheets of dielectric (nonconducting) material—oil-impregnated paper in conventional designs, plastics in the newer ones. The stored energy can be increased by raising the voltage between adjacent foils, by making the dielectrics thinner, by boosting the "dielectric constant" (the ratio of the electric field strength in a capacitor with a dielectric material to that of an empty capacitor), and by fitting more layers into a stack. The payoff can be large; if each of these factors were tripled, the stored energy would increase by a factor of 3^5, or 243.

Maxwell Labs has already made progress, boosting by a factor of 10 the energy that can be stored in a capacitor about the size of a small suitcase. The next tenfold improvement may be in hand by the March 1989 shoot-out. Under a program called Supercap, Maxwell is working with Pennwalt (King of Prussia, Pa.) to develop polymers such as polyvinylidene fluoride for use as the dielectric. These offer increased voltages and dielectric constants, along with thinner layers.

A separate DARPA program, for which contracts were awarded in December, will seek to develop key technologies for guided projectiles. Because they travel at higher speed, electromagnetic projectiles undergo higher stresses, in the barrel and in flight, than conventional artillery missiles. Ford Aerospace (Newport, Cal.) is under contract to investigate short-range unguided (or "dumb") rounds with the goal of applying this knowledge to the problems of guided (or "smart") munitions for long ranges. The DARPA effort aims at guidance and fire-control systems suitable for three tactical tasks: antitank attacks, tactical air defense, and defense against short-range missiles that may be

SETH RESNICK

Henry Kolm of EML Research, with coilgun developed for DARPA's electromagnetic gun program.

carrying chemical or nuclear warheads. The goal is not to demonstrate complete fire-control systems, but rather to build their high-risk elements, such as a highly responsive projectile autopilot that can stand up to the 100,000 g's of acceleration in the gun barrel. The fire-control system could possibly track the target and send guidance commands by laser to the projectile in flight. One problem with such a system is that a laser receiver would have to be mounted on the back of the round, where it would undergo lower stresses in flight than if it were located in the nose of the projectile. The receiver would therefore need some sort of protection while being fired.

The DARPA initiative into electromagnetic guns is moving forward strictly as

Competing designs will participate in a "shoot-out" in 1989.

an R&D program. The current goal is not to fit the gun to a particular vehicle but only to demonstrate that such guns can compete with existing chemical ordnance. The significant milestones are the 1989 shoot-out, which will select a candidate from among the leading technologies within the electromagnetic gun program, and the competition with the Army, which will take place in 1991.

Beginning this spring, however, the Army's Armament Research Development and Engineering Command (Picatinny Arsenal, Dover, N.J.) will fund studies of fighting weapons for the battlefield, specifically of those to be mounted on tanks. Some of the requirements for this program are that the munitions be chemically inert and free of high explosives (to simplify logistics and storage), and that the gun feed automatically. Finally, these new guns are to be effective against enemy armor, helicopters and other aircraft, and tactical missiles. All these requirements would be met by the electromagnetic guns being developed by DARPA. In 1991, the Army may choose some of them for its fighting tanks. □

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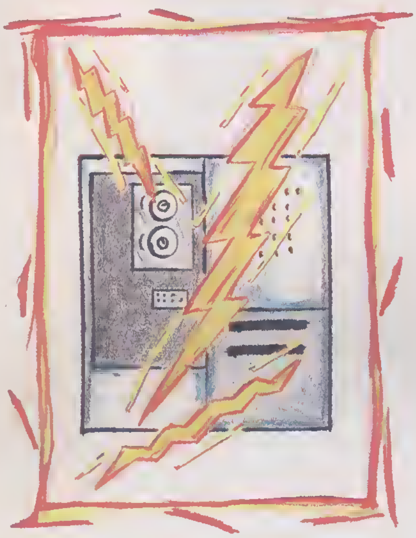
COMPUTER DISRUPTION: PLANNING FOR THE WORST

Computers are no longer merely useful adjuncts to business; corporate survival has become inextricably tied to them. Without data-processing centers, banks could survive a maximum of 48 hours, distribution companies 3½ days, and manufacturing companies about 5 days, according to a study conducted by the University of Minnesota. Yet all too often companies have adopted an "it can't happen here" attitude about the possible loss of their computer facilities. While many firms have purchased business interruption insurance, relatively few have adopted plans for postdisaster recovery of operations and equipment.



One reason is cost, which inevitably increases along with the complexity and size of the computer operation. "Real disaster recovery preparedness—something that has been tested and would work if you needed it—is expensive," says John Singel, national director of information systems consulting for Price Waterhouse. "It can increase the cost of computer operations between 5% and 25% per year."

Defining an appropriate level of preparation is complicated by the types of possible disasters—and the number of appropriate actions—ranging from the exotic to the mundane. Small fires, leaking toilets and water pipes, malfunctioning sprinkler systems, or vandalism can be just as catastrophic as earthquakes, tidal waves, tornadoes, or hurricanes if they render a critical computer useless.

Still, there are several basic ways to mitigate the effects of a disaster. The most obvious is to make copies of all critical data and application software and store them off-site. Some companies have established vaults for this backup purpose, including DataPort, which operates a 2½-acre vault snugly ensconced 100 feet below the concourse level of New York City's World Trade Center. Another, rather offbeat location for data storage is an abandoned iron mine in New York's Catskill Mountains, refurbished as a data vault by the Iron Mountain Group (Boston). Other companies offering secure off-site storage facilities include Arcus (Union City, Cal.), AT&T Data Security Services (Orlando, Fla.), and Off-Site Storage (Lowell, Mass.).

When choosing a storage site, experts suggest that companies carefully examine its security provisions, such as protection against electromagnetic interference, which can erase data stored on magnetic media. The site's physical construction should also be evaluated, along with its backup facilities for power and for maintenance of constant temperature and humidity conditions. Another key factor is location, for ease of regularly transferring data to the site. Finally, the site should not be susceptible to the same sort of disaster that might knock out the original facility.

Off-site storage of data is critical, but data without a computer are of little value. So most disaster recovery plans include provisions for a backup computer site. This can be a "cold" (or "shell") site, replete with raised floors, fire protection, backup power, air conditioning, and cooling water, but without the computer. The alternative is a "hot" site, equipped with a compatible computer.

Among the companies that offer hot or cold backup sites are Comdisco Disaster Recovery Services (Rosemont, Ill.), Digital Equipment (Stow, Mass.), El Camino Resources (Sherman Oaks, Cal.), and Sungard Recovery Services (Wayne, Pa.). A potential problem with this approach, however, is that the sites are used by several firms, which are provided for on a first-come, first-served basis—an unworkable arrangement should a disaster knock out a number of companies signed up for the same facility.

Alternatively, one company can use another's facilities if necessary; such plans obviously require that all the computer facilities be compatible. A final option is for a company to set up its own multiple data-processing centers. This route is the most expensive, but also the most secure.

Frequently overlooked in such plans are assured telecommunications networks. "A company needs a reconnection capability as well as a computer backup," says Singel, "and both should be in place ahead of time."

Depending on the telephone company for swift installation of lines to the backup site is considered less than prudent, since the job can take more than a month to accomplish. Possible alternative solutions include moving key communications nodes away from the major data centers, installing multiple nodes to provide alternate routing capabilities, or calling on a provider like Premiere Network Services (Dallas), which bills itself as the first telecommunications disaster recovery company. "We can relocate and restore a network in 24 hours in any of 32 cities in the

PAUL WESTON

by Sam Diamond

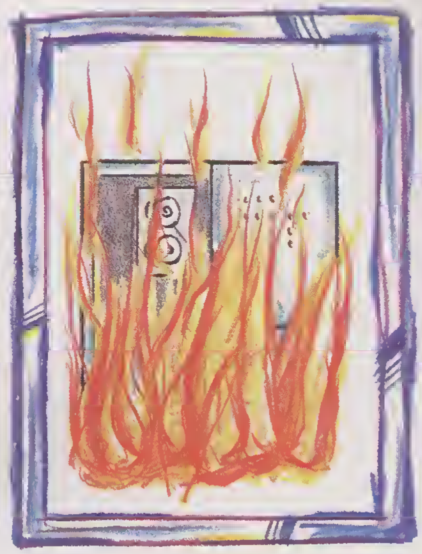
eastern two-thirds of the U.S.," claims Leo Wrobel, Premiere's president. Premiere's sites are essentially like computer backup hot sites that are outfitted with telecommunications equipment rather than with a mainframe.

Resuming operations quickly through backup facilities is only part of the disaster recovery process, however. A company should also establish procedures for restoring its damaged facilities, which include not only walls, floors, and ceilings, but also computers, hard disks, and magnetic tape.

The advantages of restoring computers and other electronic equipment are twofold. For one thing, restoration almost always takes less time than replacement. "In a week, we can clean a mainframe computer that might take six weeks to replace," says Ken Greenough, president of Restoration Technologies (Campbell, Cal.). And for another, the cost is significantly lower. "We generally can restore equipment for 10–20% of its replacment value," says Bob Schubert, president of Relectronic Service (Hackensack, N.J.), a Siemens AG subsidiary that specializes in restoring electronic equipment.

Given these advantages, restoration is becoming a popular road to recovery. Because of the increasing value of computer equipment, "insurance companies find that when they look at a computer that's full of water, they are no longer in a position where they can decide to buy a new one on the spot," says Greenough.

Still, electronic equipment restoration is no simple task. "We don't just dry up the mess and wipe it off," says Schubert. The art and science of restoration are complicated by the fact that damaged equipment often has to be totally dismantled to clean every circuit board, solder joint, and interconnect. Thus familiarity with high tech electronics is essential. A thorough knowledge of chemistry is also needed to determine the nature of the contaminants, as well as to decide on the best cleaning solutions and mechanical techniques for removing them. Despite the difficulties, results are generally quite good. "In 99% of the cases, we can bring equipment back up," claims Rankin Ahlm, president of HazTran (Grand Rapids, Minn.).



Magnetic storage media can also be restored with techniques analogous to those used in restoring computers. Here, speed is of the essence. "The sooner you get any kind of contaminant off the disk packs and tapes, the better the chance of

Restoration almost always takes less time than replacement, and the cost is significantly lower.

recovering the media," says Dennis Haskamp, Chicago branch manager of Scopus (Lowell, Mass.), a tape-cleaning firm.

In the end, a carefully conceived and tested plan, developed *before* a disaster occurs, can mean the difference between financial ruin and a minor setback. "Disaster plans can't prevent the disasters from happening," says Relectronic's Schubert, "but they can help companies recover quickly after they occur." □

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WILL ASIAN SOFTWARE FLOOD U.S. MARKETS?

CAROL O'MALIA

As the production of computer hardware moves from the United States to the Far East, the American microcomputer industry consoles itself with the thought that at least software will always be American.

But will it? Could software—and software profits—go the way of floppy disk drives and memory chips, drifting steadily, seemingly inevitably, eastward? Or is software more like television programming, which demands such cultural understanding and resources that no foreign producer can hope to compete in the American market?

It is too soon to know for certain, but the American computer industry has little reason to be smug. Consider this possibility: software could divide into two forms—high-priced, state-of-the-art products that would remain largely American, and mass-market products that could be made almost anywhere. Several trends in the worldwide microcomputer market point the way toward software that could be written in Asia, or American software that could be distributed so cheaply by Asians that U.S. developers would see few profits.

Software has remained largely an American enterprise for a variety of reasons. First, the U.S. microcomputer industry has progressed so fast that foreign software writers have been unable to keep up. News of the IBM PC's dominance in the American market in 1982 took more than a year to reach other continents. Second, two prime advantages of manufacturing products in Asia (except in Japan)—cheap labor and cheap hardware components—are of little use in software development. Japan owes much of its success in high tech fields to its hardware manufacturing skills, which do not apply to software. Third, within Asian markets (again, except in Japan), software is so routinely pirated that software development must seem foolhardy to local business people. And, of course, there are immense barriers of language, culture, and everyday business practice.

by Cary Lu

The relatively high cost of computer hardware compared with income in both Europe and Asia tends to discourage students and others from taking up microcomputer programming, whereas the ready availability of hardware in the United States has encouraged it. Even Europeans have had a hard time penetrating the American software market, although the language and cultural barriers are not as severe as for Asians.

The problems have been largely bidirectional, at least with respect to Japan; except for the MS-DOS operating system, development tools such as computer languages, and the Lotus 1-2-3 and Multiplan spreadsheets, American software has not done particularly well in Japan.

But these patterns could change. While foreign companies have failed to sell software to Americans in the past, there are several reasons why they could succeed in the future:

• *Standardized software interfaces.* For the first time, the microcomputer industry is adopting a standardized software interface. Based on work at Xerox's Palo Alto Research Center, this interface is best known through the Apple Macintosh and Microsoft Windows for the IBM PC. For purely text applications, an older interface developed for VisiCalc and now most visible in Lotus 1-2-3 is also something of a standard. With standardized interfaces, software writers no longer have to invent one, and users do not have to take on a major relearning process when they move from one program to another.

• *Hardware stability.* The IBM PC has been a fairly stable product since 1981; newer models with 80286 and 80386 processors have maintained software compatibility. This stability, replacing the rapidly changing market preceding IBM's entry, makes software investments more practical. The Macintosh has a shorter history, but it, too, has remained stable since its introduction.

• *Low-priced computers.* The proliferation of IBM PC clones has driven prices well below $1000 for a complete system. People who spend so little money for hardware do not want to spend much money on software. Macintosh hardware prices have stayed relatively high since Apple is the sole supplier, but a clone would push prices downward. (The system software built into the Macintosh has discouraged clone makers so far, but as Apple improves its market position, someone will take on the difficult task of replicating a Macintosh.)

• *Bundled software.* The cheapest way to distribute software is to bundle it with a computer. Bundling has not been a major factor among IBM PC clones but will become one as the clone wars intensify. Bundled software is almost the only feature, aside from price, that can distinguish clones; the hardware offered by large Asian manufacturers now entering the U.S. market is essentially identical.

Bundled software could come from two sources. First, an Asian software producer could write it. By now, enough foreign graduates of American engineering and business schools have acquired sufficient expertise to develop effective software

back in their native countries. The software need not become a hit product; it merely needs to work adequately, show a standard interface, and be cheap enough to bundle with hardware. Foreign governments may even sponsor such software, much as the Taiwan government sponsors and licenses a low-cost rewrite of IBM's input/output routines so that local makers can produce cheap, legal IBM PC clones.

If native software developers do not materialize, the manufacturers could get software for bundling from Americans.

The U.S. software industry has little reason to be smug: mass-market products could be made almost anywhere.

The license fees for bundling hot products like Lotus 1-2-3 will probably be too high, but a ready American source could be the many programs that perform well but were commercially unsuccessful. These "failed" programs have very low license fees; after all, some income is better than none for their developers. Thus clone makers could bundle low-cost American software that returns only a tiny stream of revenue to the software developers. If a complete computer system retailed for $700, it would wholesale for about $350; of that $350, perhaps $5 might be paid for licensing bundled software. If the bundled programs had standard interfaces, users could easily move up to higher-priced, higher-performance programs.

Of course, this bundled, mass-market software will lack depth and sophistication, lagging three or four years behind state-of-the-art products. But most users are three to four years behind anyway. The net result could be an American software industry at the cutting edge, with control of the mass-market products passing to foreign manufacturers.

Cary Lu is microcomputer editor of HIGH TECHNOLOGY.

MINI-TV CAMERAS SEND IMAGES FROM INNER SPACE

The interior of a jet engine is studied with a miniature TV system. Such mini-cameras also help physicians examine patients internally without extensive surgery.

A growing array of miniature television cameras, some measuring a scant quarter inch across, are being used to send live color images from environments once considered inaccessible. Although the cameras were originally meant for the surgical suite, they are now being adapted to such industrial applications as municipal sewer systems, computer subassemblies, and the interiors of nuclear power plants.

The tiny cameras were first designed for use with endoscopes—thin tubes, consisting of optical fibers and lenses, that are snaked into the body to provide live images of the interior. Types of endoscopes include the colonoscope (which was used, for example, to examine President Reagan for intestinal polyps), the bronchoscope (for exploring the lungs), and the arthroscope (which is inserted into injury-prone joints such as the knee and shoulder). The arthroscope has practically revolutionized sports medicine by allowing the surgeon to view and repair damaged joints through a tiny incision, thus replacing months in a cast with days wearing a Band-Aid. For example, athlete Joan Benoit won the 1984 Olympic marathon just 17 days after arthroscopic surgery on her knee.

The endoscope became even more useful with the arrival of hand-held, easily sterilized video cameras that transmit the images to a TV monitor rather than to a microscope. Besides making the procedure more comfortable for the surgeon, the cameras allow the entire medical team to view the operation, and also provide a video record of the surgery for educational or legal purposes. Another advantage is that viewing surgery via video protects the physician's eyes from the lasers that are often used as fiber optic light sources.

Minicameras are now offered by several U.S. companies, including M.P. Video (MPV) in Natick, Mass., Circon in Santa Barbara, Cal., and Medical Dynamics in Denver. A color camera produced by MPV, for example, is about the size of a golf ball, weighs less than three ounces, and is fully immersible for sterilization, according to president Mel Prenowitz. The cameras typically feature miniaturized, lightweight optics and convert images to electronic pulses through an array of charge-coupled devices (solid-state elements that convert light to electricity) rather than through a conventional electron-beam scanner; the pulses are then relayed to an imager that reconstructs the picture. Typical prices—including camera, monitor, VCR, and control unit—run between $5000 and $10,000, depending on the system's complexity and packaging. Other models are even smaller, but costlier. For example, a device from Welch Allyn (Skaneateles Falls, N.Y.) makes MPV's golfball-size camera look gargantuan: designed for use with a gastroscope or colonoscope, the Welch Allyn camera is less than half an inch in diameter and costs about $20,000.

Prenowitz sees a growing market for minicameras in industrial and scientific applications, such as the automated inspection of IC boards. Another example is the use of MPV cameras to help repair sewer pipes. The camera is contained in a small housing and mounted on a sledlike device that carries caulking material to the site of a crack located by the camera. The "sled" inflates and presses the caulk into the crack, creating a seal; the camera checks to confirm the repair, then continues down the pipe. This procedure has been used in New York and Boston.

Japanese producers such as Hitachi, Sony, and Panasonic are also active in the minivideo market—indeed, they dominate it. Prenowitz concedes that in terms of volume, MPV is no match for Hitachi. "They could manufacture during a coffee break what we do in a year," he claims.

But whereas the Japanese minicameras are generally "off-the-shelf" (and used almost entirely for endoscopy), companies like MPV compete by tailoring their systems to specific applications. For instance, *National Geographic* researchers recently used one of MPV's cameras to explore a narrow shaft in an Egyptian tomb; and a quarter-inch camera from Welch Allyn is used for examining the interiors of aircraft engines and nuclear-plant boiler tubes. MPV has also designed cameras for what it calls "low-light" conditions—inside a knee, for example, where a small amount of light is reflected from bone and cartilage—and "ultralow-light" environments, such as the sooty interior of a jet engine. □ ***—Ricki Lewis***

COURTESY WELCH ALLYN, INC.

HOW TAX REFORM AFFECTS HIGH TECH

Virtually every American company will be touched by last year's Tax Reform Act (TRA), and most will feel a bigger tax pinch than ever: the TRA is expected to increase corporate taxes by about $120 billion over the next five years. Although impacts will vary from one business to another, technology companies will fare reasonably well under the legislation, with the wins—the extension of R&D credits, for example—likely to outnumber the losses.

The reduction in the maximum tax rate (from 46% to 34%) is the biggest win for technology companies, which often have high effective tax rates. The new rate takes effect July 1, 1987, and will result in a "blended tax" for 1987; that is, a calendar-year corporation will be subject to a maximum rate of 46% in 1986, 40% in 1987, and 34% in 1988. Fiscal-year companies will be subject to other special blended rates which will vary depending on when their year ends.

Software companies are among those that stand to benefit the most from the three-year retroactive extension of the R&D credits, which technically had expired at the end of 1985. Although the amount of the credit was reduced from 25% to 20%, the TRA offers more favorable definitions for software research expenditures. Specifically, such research is now no different from any other research for the purposes of tax credits; the IRS had previously limited the credits to new or significantly improved software, and only when the software's feasibility had been in doubt from the beginning—wording that made qualification for the credit difficult.

Another victory for software developers is the exclusion of software royalties from the penalty tax imposed under personal holding company (PHC) provisions. Under pre-TRA law, PHCs (companies that are at least 50% owned by five or fewer persons and that receive income from software licensing) could be hit with a 50% penalty tax on aftertax profits, resulting in an effective tax rate of nearly 75%. The TRA, however, outlines exceptions to the PHC rules for certain royalties that are earned by an "active" software company; among other qualifications, this term refers to corporations that actually develop or produce software and receive royalties equaling at least 50% of their ordinary gross income for the year.

But the news for technology companies isn't all good. A major loss is the repeal of the investment tax credit (ITC), effective retroactively for property placed in service after December 31, 1985. However, there are rules that may exempt such property under certain conditions; for example, property acquired via written contract during 1985 but placed in service after Feb. 1, 1986, may qualify for ITC.

Losses will also result from modified depreciation rules. The TRA provides new "useful lives" for property placed in service after 1986, which must be used for determining the period of depreciation. In general, technology companies will not be badly hurt by this change, since most of their equipment will be depreciable over five years, thus providing relatively large deductions. But commercial real estate must now be depreciated over 31½ years (using a straight-line method) as opposed to the current 19-year useful life, which will reduce tax deductions for newly acquired property. As with the ITC, however, transition rules may "grandfather" property placed in service after 1986.

One of the most complex and controversial items in the TRA is the alternative minimum tax (AMT), which is in effect aimed at the many large companies that usually pay no taxes. Under the AMT, companies are required to figure taxes first under regular tax rules, then under the AMT rules, and pay the larger sum. (Under certain circumstances, the liability may later be credited against the regular tax.) As a result, companies must now keep two sets of books in order to calculate both types of liabilities, thus adding another layer of complexity to an already complicated set of tax rules.

There are two differences between the regular and the AMT systems: first, the AMT system covers items not included in the regular tax system, such as income deferred through installment sales and certain types of accelerated depreciation. As a result, the AMT income may be significantly greater than the income computed under regular rules. The second difference is that regular taxable income will be subject to a 34% tax rate, while the AMT rate is 20%.

Other important changes for technology companies involve divestiture, mergers, and acquisitions. For example, the tax costs to individual shareholders selling their companies has risen dramatically. Until recently, shareholders could sell a company's assets at noncorporate tax rates, then liquidate the company with only a 20% maximum capital-gain tax rate; beginning this year, however, such sales are taxed at both the corporate and shareholder level. As a result, the effective tax rate for an individual shareholder selling his business will rise from a maximum of 20% to approximately 52%. In addition, the maximum individual capital-gain rates have climbed from 20% to 28%.

Finally, there are new rules on the acquisition of corporations with net operating losses (NOLs) that could adversely affect investment tax credit carryforwards and other advantages. The reason is that the TRA limits the tax benefits of such carryforwards if there is a significant change in ownership of a company with an NOL over a three-year period. The problem is that the ownership criterion could also be satisfied by a company that goes public, which could in turn restrict or eliminate the company's utilization of NOL or ITC tax benefits. The TRA imposes a complicated set of rules here, which must be closely studied before making any significant ownership changes. □

—George J. Yost III, Coopers & Lybrand

WRITABLE OPTICAL DISCS FOR PERSONAL COMPUTING

This could be the year that writable optical discs move out of the laboratory and onto the desktop for personal computers. Optical disks offer much more storage capacity—more than 500 megabytes on a single disc—than the conventional floppy magnetic disk, but the currently available compact discs function only as read-only memory (CD-ROM—see HIGH TECHNOLOGY, Oct. 1986, p. 44). While CD-ROM is satisfactory for storing databases that do not require frequent updating, many computer applications, such as financial databases, call for writable discs. The new optical drives are expected to be multifunction—able to read or write a variety of disc types. One manufacturer, Optimem (Sunnyvale, Cal.), has announced such a drive, and others are expected to follow later this year or early in 1988.

A conventional CD-ROM drive can read only data prerecorded on compact discs, similar to those used for audio reproduction. Storage on the disc is in the form of tiny pits that can be sensed by a laser scanning head. With a write-once disc, data are recorded by a laser that melts tiny holes in a thin, vacuum-deposited metal film. Once written, the data cannot be erased but can be read many times without deterioration—hence the drives are known as WORM (write once, read many) drives. The data written on a WORM disc can be read by a laser scanning system similar to that of a conventional CD-ROM drive.

Research into erasable optical media has been going on for many years at such companies as Philips (Eindhoven, the Netherlands) and 3M (St. Paul, Minn.). The principal technologies under development are magneto-optic and phase transition, according to Gary Thomas, head of Philips's optics department. In magneto-optic systems, a spot on the disc is magnetized in such a way that light reflected from it will be slightly polarized. The data can be read optically by sensing the direction of polarization, and may later be erased magnetically as well. This is the technique that will be used in the first commercially available erasable discs.

In phase-transition media, the heat of the laser converts a spot on a surface from a crystalline to an amorphous state, in which it can be detected optically with a laser light source. The amorphous spot can be returned to crystalline form to erase the data by a further application of heat from a laser beam. Still in the laboratory research stage, phase-transition media are unstable and prone to fatigue, report researchers at Philips.

Later this year, Optimem expects to have a 5¼-inch drive that can read CD-ROMs, and write and read both WORM and erasable media, according to Larry Fujitani, director of marketing. The same laser scanning head can read both permanent and erasable media. "Multifunction drives will carry price tags of $2000 to $3000 at first," says Fujitani, "declining to around $1000 once volume shipments begin." Other manufacturers will follow in 1988, probably led by Maxtor (San Jose, Cal.) and Optical Storage International (Colorado Springs, Colo.). Japanese vendors, notably Sony and Hitachi, are also expected to follow along during 1988.

Even smaller drives are under development, notes San Francisco–based consultant Edward S. Rothchild. As 5¼-inch multifunction drives become established toward the end of this decade, he says, there will be 3½-inch multifunction drives aimed at portable computers, possibly from IBM. According to Rothchild, IBM has an optical storage system under development but has yet to announce any products in this field. IBM's endorsement of a specific optical medium would speed the adoption of standards for optical storage systems.

From the user's standpoint, multifunction optical drives may be a little ahead of their time. "There's no demand for combined CD-ROM and WORM drives," says industry watcher Steven Weissman of Communications Publishing Group (Natick, Mass.). Weissman looks for erasable media and drives to appear this year, but he doesn't expect users to require erasability in addition to WORM and CD-ROM anytime soon. The capacity of WORM discs is so enormous—up to 2 gigabytes—that there is no need for erasability, he says. "Just update the information on another part of the disc and tell the computer to ignore what's been written before." Meanwhile, says Weissman, the earlier data are still there and can be retrieved. □

—James F. Donohue

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ASPECT TELECOMMUNICATIONS:

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For businesses that receive a very large number of phone calls (1000–50,000 a day), Aspect's CallCenter provides a variety of functions that make life easier. It includes a digital telephone switching system that uniformly distributes incoming calls to customer telephone agents or service representatives, a voice storage and retrieval system, a telephone set with built-in tutorials for agents and supervisors, and management consoles. A unique feature of the system is a statistical analysis package that can help forecast the number of people needed to staff the phones.

Aspect targets three major areas: direct-mail catalog sales orders, financial services, and telephone technical support for products such as personal computer software. Its primary competitors are Teknekron Infoswitch Corp. (a manufacturer of analog call distributors) and a Rockwell International division that offers switching systems.

Financing: $11 million from investors including Mayfield Fund; Matrix Partners; Merrill, Pickard, Anderson & Eyre; Menlo Ventures; Horsley Kehoe; Security Pacific Capital; Asset Mangement; Stanford University; and several individuals and investment partnerships.

Management: James R. Carreker (president and CEO) was senior vice-president and general manager of Dataquest's Information Systems Division, John D. Meyers (vice-president of engineering) was director of advanced technology and hardware development for Datapoint's Communications Management Products Division, and Byrne O. Benfield (VP of software development) was president of Mesquite Software.

Location: 1733 Fox Dr., San Jose, CA 95131, (408) 279–5511.

Founded: August 1985.

Aspect's TeleSet has a "help" key and a built-in tutorial to assist the user in operating procedures.

INTERACTIVE MEDICAL COMMUNICATIONS:

Training industry in safety standards

To help industry familiarize its workers with Occupational Safety and Health Administration regulations, Interactive Medical Communications (IMC) has designed interactive laser disc training programs. These focus on areas such as asbestos removal and disposal, respiratory equipment maintenance, and forklift operations. The IMC system comprises a laser disc player, an IBM-compatible computer, a high-resolution monitor, software, and a touchscreen, which can be bundled in a kiosk supplied by the company. A worker can request information without prior computer knowledge by simply touching choices on a screen.

IMC recently completed training programs for more than 400,000 General Motors workers and 40,000 New York City Transit Authority workers. In early 1987, IMC was awarded a contract with OSHA to provide training for over 4 million government employees.

Financing: Seed capital was raised internally.

Management: James L. Mason (president and founder) wrote, produced, and hosted *Body Politics*, one of the first TV consumer health series, for Westinghouse Broadcasting. Doug Jeffrey (vice-president of marketing) was vice-president of sales at Gold Hill Computer, Henry L. Berman (VP of product development) was manager of training programs for The Foxboro Company, and Robert B. McDuffee (VP of software development) was a senior analyst and project leader at UAI Technology.

Location: 100 Fifth Ave., Waltham, MA 02154, (617) 890–7707.

Founded: February 1984.

OPTEX BIOMEDICAL:

Blood tests in real time

A fiber optic device that will enable doctors to monitor patients' blood continuously has been developed by Optex Biomedical. The proprietary device, called an optode, is a thin, disposable bundle of fibers that is inserted into a person's artery like a catheter. At the tip of the fibers are three sensors that detect the concentration of oxygen and carbon dioxide in the blood, as well as pH. Thus doctors can note changes in these parameters immediately, rather than waiting for laboratory results. Optex is currently targeting the optode for hospital intensive care; it hopes to market the device by 1988. The company is also investigating similar products for detecting enzymes and blood sugar.

Financing: $1 million from SMN Associates and the U.S. Air Force School of Aerospace Medicine (initial research grant at Texas A&M in 1983).

Management: Steven Spar (president), David Costello (inventor & VP of research and development), and Les Schlain (VP of product development), each with MS degrees in bioengineering from Texas A&M, cofounded Optex with Mark Abrams (VP of engineering), who earned his MS in electrical engineering at Northwestern University.

Location: 2611 FM 1960 W, Suite C 100, Houston, TX 77068, (713) 580–6789.

Founded: August 1984.

—Margaret Woisard

APPLICATION-SPECIFIC CHIPS FIND WIDENING USE

Demand for application-specific integrated circuits (ASICs)—chips that can be customized to meet user needs—has been rising rapidly in recent years for several reasons. Chip design software and workstations are more sophisticated, design costs and turnaround times have dropped, and vendors of computers and electronic equipment increasingly seek specialized chips with which to differentiate their products. ASICs currently represent 11% ($2 billion) of the $18 billion worldwide market for integrated circuits, according to Hambrecht & Quist (San Francisco), and are expected to rise to 25% ($8 billion) of an approximately $30 billion market in 1990. A variety of ASICs are being produced, the simplest of which are programmable logic devices (PLDs) and gate arrays. (Cell-based designs and fully customized chips are the other categories of ASICs.)

PLDs combine the best of two worlds: like general-purpose, off-the-shelf chips, they can be manufactured in volume and thus offered at a low cost ($2–$4 each). They can also be reconfigured, within limits, by the user, or easily replaced in the field to accommodate upgrading and software changes, even after a product has been shipped. In addition, by using PLDs, equipment firms can reduce the number of standard chips on their printed circuit board assemblies by a typical ratio of 10 to 1, with consequent savings in space and power requirements. PLD revenues should rise from an estimated $350 million last year to $800 million in 1990. In contrast to PLDs, gate arrays, the next level of ASIC complexity, can only be customized by the vendor in the factory; because of their more efficient power consumption, gate arrays also entail even further savings in the size and weight of equipment in which they are used. The improved reliability of such devices makes them appealing for military and aerospace applications. Gate array revenues should climb from $800 million in 1986 to almost $4 billion in 1990.

Several major semiconductor firms, including Texas Instruments, National Semiconductor, and Advanced Micro Devices (AMD), offer products in these markets. But the leading company in PLDs is Monolithic Memories (Santa Clara, Cal.), while LSI Logic (Milpitas, Cal.), leads in gate arrays.

Offering more than 30 kinds of PLDs, **MONOLITHIC MEMORIES** (OTC: MMIC) accounts for approximately half of the current market for such circuits. Monolithic's products are manufactured using either bipolar technology, which results in high-speed chips suitable for microprocessor and minicomputer applications, or CMOS (complementary metal-oxide semiconductor) technology, which produces PLD chips with increased density and lower power requirements.

Monolithic Memories' Joel Rosenberg designs a PLD, an application-specific chip that can be reprogrammed by the user.

In a move undertaken several years ago to reassure customers that they would not be dependent for critical products on a then-small, sole-source supplier, the company began licensing its products to competitors such as AMD, National Semiconductor, and Motorola. Monolithic, however, has remained the preferred source of PLDs, thanks to its reputation for efficient customer service, the breadth of its product line, and the dominance of its PLD architecture.

Monolithic's revenues last year were $205 million, with profits of $8.9 million and 43¢ earnings per share. Revenues in 1987 should increase to an estimated $221 million in revenues, with profits dropping to $5.9 million and earnings per share to 27¢, because of price competition and high R&D expenses.

LSI LOGIC (OTC: LLSI), which entered the market for gate arrays 10 years after the first commercial products of this type became available, has since climbed ahead of its several dozen competitors. The company is known for pioneering work in several areas. In chip packaging, LSI has devised more than 200 package types to handle the increasing complexity of lead connections required to transmit signals into and out of gate arrays. The company has also developed simulation software that enables it to test how well gate arrays work with other electronic components in a customer's product. In addition, LSI is offering a line of channel-less gate arrays, developed with a new technique that makes more efficient use of the entire area of a chip for designing logic elements. This method, known as sea-of-gates technology, thus allows much greater density than that found on a conventional array, while retaining the latter's advantages of low cost and quick production turnaround. In addition, LSI provides 26 simulation and design centers around the world that train customers to design their own gate arrays, as well as more complex circuits, with or without the help of LSI's engineers.

The company made $3.8 million in profits last year, with 10¢ earnings per share, based on revenues of $194 million. Profits in 1987 will jump to an estimated $14.6 million, and earnings per share to 44¢, based on $250 million in revenues. This improvement is expected because the company is shifting production from low-complexity arrays (in which competition is heavy) to more complex, and more expensive, devices (where LSI could effectively define its own niche). □

by Millard Phelps

Millard Phelps is a senior technology analyst at the San Francisco–based investment banking firm of Hambrecht & Quist.

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